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Economic Analysis of Wet Versus Dry Ash Disposal Systems

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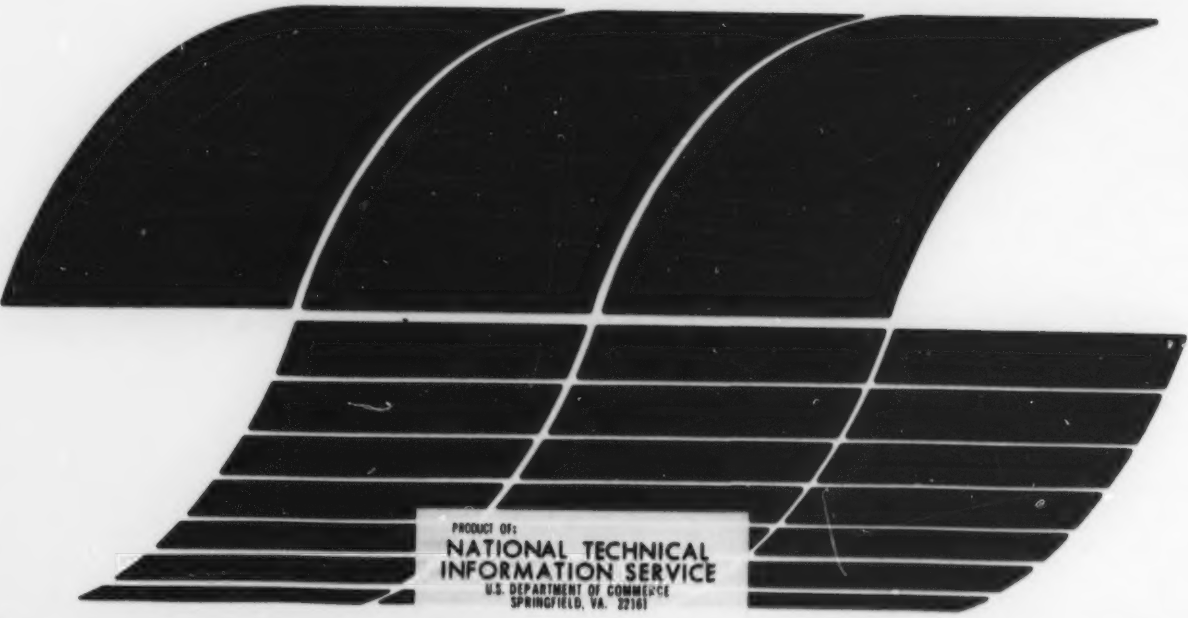

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16. ABSTRACT The report gives results of an analysis of the economics of both wet and dry methods of coal ash disposal, under a specific series of assumptions. It indicates trends in ash disposal costs and includes an evaluation of system components including: in-plant handling systems (vacuum, pressure), transportation systems (pipeline, truck, conveyor, pneumatic systems), disposal area (flat topography, narrow valley, wide valley), and environmental/engineering considerations (liner vs. no liner, compaction vs. no compaction). The effect of power plant size (300, 600, 900, 1300, and 2600 MW) was also evaluated. For each case considered, capital and first year operating and maintenance costs were calculated, then evaluated over the estimated 35-year plant life, using both present worth and total system cost analyses. Study conclusions included: of all factors considered, site topography has the greatest influence on ash disposal costs; dry disposal is the least-cost alternative for flat sites and for many valley sites; and for small plants or short hauling distances, truck transport is the least-cost alternative for dry ash disposal.

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ABSTRACT

The objective of this study was to evaluate the economics of alternative methods of coal ash disposal for a new, coal-fired power plant. Specifically, wet versus dry methods were compared by evaluating the economic impact of each system component. These system components included in-plant handling systems, transportation systems, and disposal area design. In addition to the component by component analysis, various plant sizes were compared. These include 300 MW, 600 MW, 900 MW, 1300 MW, and 2600 MW powerplants.

To provide for a reasonable economic comparison, each disposal system alternative was analyzed for each power plant size. Capital and first year O&M costs were calculated. These costs were then evaluated over the estimated 35-year life of the plant by both present worth and total system cost analyses. Present worth analysis was utilized due to its current use in engineering economic decisions. Total system cost analysis was utilized to indicate the effect of borrowed capital over the life of the system.

The result of these analyses was an economic comparison that indicates trends in disposal costs, but does not provide the level of detail necessary to select a disposal system for a specific site. System selection can only be accomplished by a detailed analysis of site specific parameters.

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SECTION 1

EXECUTIVE SUMMARY

The purpose of this report is to analyze the economics of both wet and dry ash disposal systems for new, coal-fired power plants, under a specific series of assumptions and to provide an indication of trends in ash disposal costs. Knowledge of these trends in disposal system costs will ultimately aid in the identification of a least cost ash disposal system for a specific power station. A secondary purpose is to provide background information concerning ash disposal system design and selection. Although a specific range of power plant sizes and characteristics was analyzed, the results of these analyses have been reported in terms of cost per dry ton of ash disposal and will be generally applicable to other disposal situations.

An economic analysis of wet and dry disposal was performed for a series of coal-fired power plants (300 MW, 600 MW, 900 MW, 1300 MW, and 2600 MW) burning subbituminous coal with a 20 percent ash content. The analyses included in-plant handling systems, transport, and disposal site alternatives. In-plant ash handling systems analyses included vacuum and pressure pneumatic systems for fly ash and hydraulic handling systems for bottom ash. Transportation analyses, which was only accomplished for a one mile haul distance, included truck, pipeline, belt conveyor, and pneumatic conveyors. Disposal site alternatives, in addition to the general classification of wet and dry, included wide valley, narrow valley, and flat areas with both high and low height disposal schemes.

The analyses indicate that the economic selection of an ash disposal system is primarily influenced by site topography. Dry disposal is always the least cost alternative for a flat site. Valley disposal sites, on the other hand, may be most amenable to wet disposal, if suitable site conditions exist. Wet versus dry disposal economic comparisons for valley disposal sites are sensitive to variations in in-plant handling costs and disposal site construction phasing. Other interpretations of the data utilized herein could result in dry systems appearing to be the least cost alternative for valley sites. This assumes that the valley site can be developed for wet disposal. The selection of a least cost disposal system was also affected by other parameters. These included method of economic analysis, method of transport, degree of compaction, size of plant, etc. However, these considerations were typically secondary to site topography.

Although primarily influenced by topography, the other aforementioned parameters can significantly alter the selection of a disposal system based on site, utility or geographic considerations. These considerations can either negate the use of a system or provide significant economic incentives or restrictions to a disposal system. However, for the general ash disposal situations reviewed, the above conclusions are valid.

The economics of ash transport are dependent on the mode of transport, ash quantities, and distance. This interdependence results in various transport modes providing least cost alternatives under varied conditions. Pipeline transport is only applicable to wet disposal. Where dry ash disposal is practiced and when ash is produced in small quantities, truck transport is the most economical. However, as the quantity of dry ash increases, belt and pneumatic conveyor transport systems become the least cost alternatives. Although cost effective in some situations, the use of a conveyor transport system requires a long-term commitment to justify the large capital investment required.

Ash in-plant handling systems costs are also dependent on the quantity of ash handled, plant configuration, pollution abatement equipment design, total number of ash hoppers, transport distance, and other plant specific criteria. Specific plant information was unknown at the time of the study, so generalized assumptions were made. The analysis did show that a vacuum collection system is the lowest cost option, although it is typically only applicable to wet disposal. Pressure, in-plant systems were utilized for the dry disposal options due to the need for longer transport distances. Dense phase systems were more expensive than vacuum systems and less expensive than pressure systems. However, the estimates for the dense phase system were extrapolations from experience with materials other than ash; therefore, these costs were not included in the final analysis. Although this report presents generalized ash handling costs, a detailed analysis of ash handling systems should be performed for each proposed power plant size and configuration.

SECTION 2

INTRODUCTION

The selection of an economical ash disposal system is a practical means of reducing the overall cost of electrical generation. The selection process incorporates a number of pathways and alternatives which must be considered in arriving at a least cost disposal alternative. It is the purpose of this report to analyze the costs associated with these alternatives, under a specific series of assumptions, in order to provide an indication of trends in ash disposal costs. This report will aid in the selection of an ash disposal system for a specific power station. The primary objective of this study was the selection of a least cost alternative subject to a lower bound of expenditures defined by good engineering design, environmental regulations, and other considerations which must be made to provide an acceptable ash disposal system. Although ash utilization is an effective method for reducing the economic impact of ash disposal, its use was not included in this study.

In this report, an ash disposal system is defined as consisting of the following major components:

- Ash handling system;
- Ash transport system; and
- Ash disposal site.

There are various alternatives within each ash disposal system component. Economic comparisons for these alternatives are based upon disposal system conceptual designs. In turn, these designs reflect a number of design parameters, including plant size and configuration, ash quantities, and environmental regulations. Conceptual designs developed for this report are conservative in nature, thereby providing a "safety factor" in disposal system operation. Safety factors may include redundancy of equipment, i.e., three 50 percent capacity pumps, a complete backup system, and/or the use of emergency procedures, such as hiring additional transport trucks, to insure uninterrupted ash removal from the generating station. Where possible, manufacturers and utility personnel were consulted to verify conceptual designs utilized.

A primary differentiation in an ash disposal system is whether the system is wet or dry. A wet system typically consists of hydraulically transporting ash to an ash disposal pond. A dry system consists of dry ash transport to a landfill. Another major ash disposal system difference is in the topography of the disposal area. The topography may be flat or a wide or narrow valley. Each topographic configuration has different design requirements, and consequently different costs. This report and cost estimates are for new ash disposal systems with disposal sites located one mile from the power station. Longer transport distances would raise the costs for all the alternatives but are beyond the scope of this report.

A number of ash disposal systems were reviewed and cost estimates prepared. These estimates were based on specific assumptions enumerated in Appendix A. It was the intent of this study to provide an economic comparison for a typical power plant under average conditions. The result was an economic comparison that indicates trends in disposal costs, but does not provide the level of detail necessary to select a disposal system for a specific site. System selection can only be accomplished by a detailed analysis of the site specific parameters described in Sections 3 through 8. System costs were compared utilizing both a total system cost approach and a present worth method of analysis.

SECTION 3

DECISION PARAMETERS

INTRODUCTION

The selection of an ash disposal system incorporates a number of diverse and complex parameters. This section will provide an overview of these parameters, and briefly indicate how they influence the selection and design processes.

Decision parameters can be placed in the following major categories:

- Ash quantities and properties;
- Physical/economic considerations; and
- Environmental/regulatory considerations.

These categories will be explored in the following portions of this section.

ASH QUANTITIES AND PROPERTIES

Ash quantities and properties, both physical and chemical, determine the type and size of ash handling, storage, transport, and disposal systems; provide an indication of the environmental impact associated with ash disposal; establish overall system constraints; and influence disposal site design. A number of factors, including type of coal burned, degree of coal cleaning, degree of coal pulverization, type of boiler, and method of ash collection, influence the quantity of ash produced and the ash characteristics. Although some factors influence ash production more strongly than others, their combined impact on ash generation and disposal must be considered. Further, an assessment of possible changes in ash production, which might result from changes in the coal type or source, boiler retirement, or changes in ash collection equipment, should be made in the selection and design of ash disposal systems.

It should be noted that ash data for a new generating station is sometimes assumed to be similar to that of an existing plant burning a similar coal. While this may be true, relatively minor changes in factors which influence ash production can substantially change the characteristics and quantities of ash produced. Therefore, actual plant data, if available, should be used in detailing the final design of ash disposal systems.

Ash Quantities

A determination of the quantities of ash requiring collection, handling, transport, and disposal is necessary for system design. The quantity of ash produced can be estimated from the following:

- Quantity of coal burned, average lifetime and daily maximum;
- Ash content of the coal;
- Boiler type, and ratio of bottom ash to fly ash; and
- Fly ash collection system efficiency.

Peak ash production rates (tons per day at 100 percent capacity factor) are often used to size ash handling and transport systems. However, the average ash production rate, which considers the projected plant capacity factor over the operating life of the plant, is used to size the disposal site.

Ash Physical Properties

During the design, construction, and operation of ash disposal systems, there are several physical properties which warrant consideration. These include:

- Specific gravity;
- Grain-size distribution;
- Moisture content;
- Density;
- Shear strength;
- Permeability;
- Capillary rise;
- Abrasion; and
- Temperature.

The testing of these properties is defined by either the American Society of Testing Materials (ASTM), American National Standards Institute (ANSI), or the American Association of State Highway and Transportation Officials (AASHTO). Specific test methods relative to ash are described in the EPRI Fly Ash Structural Fill Manual (1).

Testing of an ash to determine these physical properties provides basic information necessary for the design of ash transport and disposal systems. In some cases, conservative design values, based on previous testing of similar ashes, can be used to expedite preliminary planning and design of ash disposal schemes. Additional testing, including a geotechnical evaluation of subsurface conditions, may be required when ash is to be placed in a landfill or embankment.

Specific Gravity

Specific gravity is the ratio of the density of solids to the density of distilled water at four degrees centigrade. Specific gravity is commonly used in calculations involving the in-place density and compaction of ash. In addition, specific gravity of ash is of particular importance since it is related to the rate of settling. The rate at which ash settles influences the degree of solids removal from sluice water passed through an ash disposal pond, or from runoff from ash landfills routed through a sedimentation basin. Testing for specific gravity is defined by ASTM D854-58 and AASHTO T100-74.

Grain-Size Distribution

The proportion of particle sizes for a specific material, within a series of specific size intervals, is described by the material's grain or particle size distribution. The determination of this distribution is helpful in describing some properties of the material. Subsequently, grain-size distribution is important in the design of ash handling systems, dry disposal sites, and utilization schemes. Grain-size distribution may be a primary design parameter when bottom ash is used as a drainage blanket or filter, when fly ash is used to "choke" aggregate prior to the placement of concrete or asphalt, or when utilized in the design of an ash transport system. This is further described in Section 5. Testing for grain-size distribution is defined by ASTM D422-73 and AASHTO T88-57. Typical values for bituminous coal fly ash and bottom ash are shown in Figure 3-1. At this time, little data exist to describe the grain-size distributions of sub-bituminous and lignite ashes.

Moisture Content

The moisture content of an ash, expressed as a weight percentage of total dry weight, is of interest because it influences both the weight and behavior of the ash. There are two moisture contents which are important in the design of ash disposal or utilization systems: natural or in-place moisture content and optimum moisture content. The unit weight of ash is affected by moisture content; increasing the moisture content increases the weight to be transported and, therefore, increases the cost of transport. The flowability of ash is also a function of moisture content. If the actual moisture content of the ash varies appreciably, the ability to make the ash flow, in either pneumatic transport systems or gravity transfer operations, may be substantially altered. Moisture content is tested in accordance with ASTM D2216-71.

Density

Density, the weight per unit volume of ash, is important because it influences the method and cost of ash transport and is also related to engineering properties of ash. In general, as the density of a specific ash increases, so does its shear strength. Alternately, permeability decreases as density increases.

The maximum dry density of an ash can be determined from laboratory testing. Laboratory tests include proctor tests, both standard (ASTM D698-70 or AASHTO T99-74) and modified (ASTM 1557-70 or AASHTO T180-74), which are utilized to define the moisture density relationship, and the relative density test (ASTM D2049-69). Field tests are also available to determine in-place density. Field density methods include the sand cone, densometer, and nuclear.

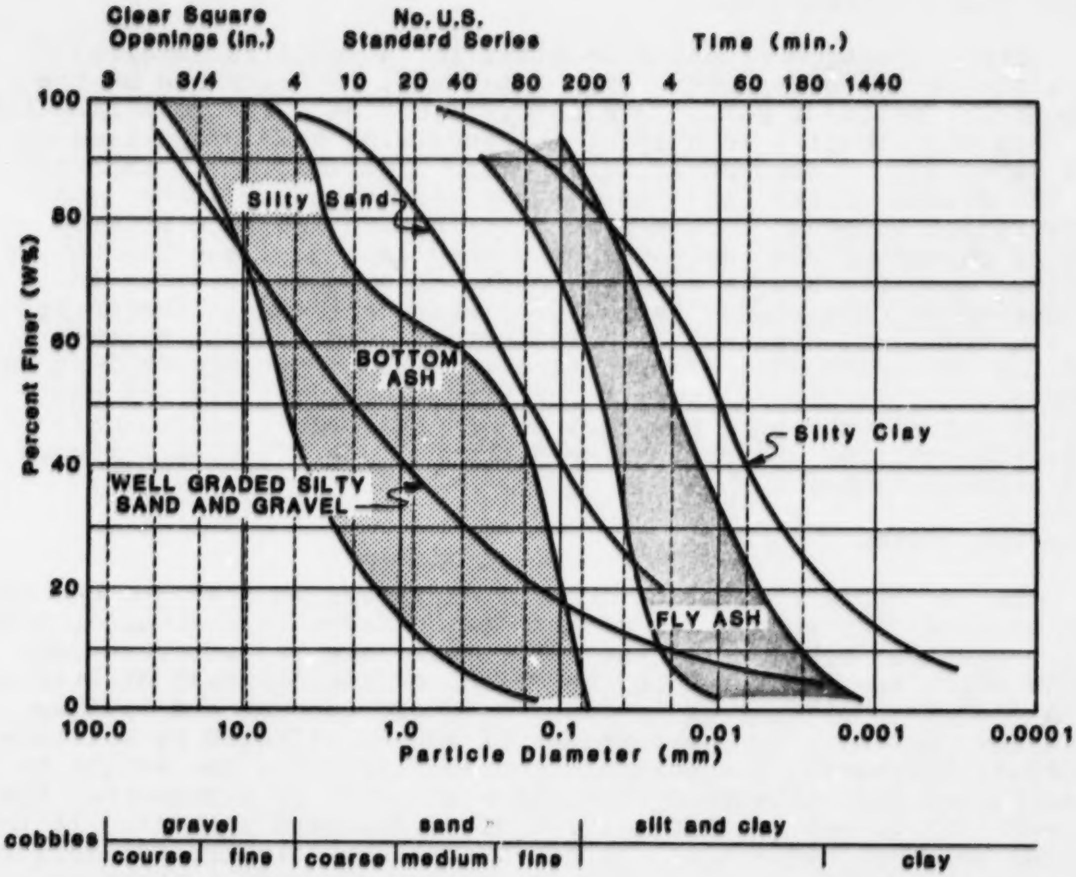

FIGURE 3.1 - RANGE OF TYPICAL ASH GRAIN-SIZE CURVES

Source: J. H. Faber and A. M. DiGiola, Jr. Use of Ash for Embankment Construction. Presented at the Transportation Research Board Annual Meeting, January, 1976 (2). and Seals et.al., 1972 (3).

Shear Strength

The shear strength of an ash is a consideration in both the design of ash fills and ash handling or storage systems. Shear strength is due to the combined effect of two engineering properties: cohesion and angle of internal friction. Cohesion is a measure of the shear strength developed by the attraction between individual particles. The angle of internal friction is a measure of the frictional resistance between particles. Standard ash analyses for soils engineering applications assume that the cohesion of the ash is negligible or zero, such that the shear strength of the ash is equal to that strength caused by the angle of internal friction. By comparison, ash analyses for material handling applications must design for both angle of internal friction and cohesion. Although many ashes exhibit some degree of cohesion during analysis, this cohesion is normally referred to as "apparent cohesion." "Apparent" is used because there is a loss of cohesion at either very high or very low moisture contents. Therefore, the shear strength of an ash, based entirely on the internal angle of friction, will determine the steepness of fill slopes which can be safely constructed. In the case of ash transport it is the actual shear strength of the material, a function of angle of internal friction, and apparent cohesion that must be exceeded in order for the ash to flow. Although geotechnical engineers may design for the conservative case, material handling engineers must know the actual ash operating conditions to provide a workable system. Specific design parameters relating to shear strength include moisture content and grain-size distribution. Shear strength may be analyzed by unconfined compression (ASTM D2166-66), direct shear (ASTM 3080-72), or triaxial shear (ASTM D2435-70).

Permeability

Ash permeability is an important design parameter in both wet and dry systems. Permeability is defined as the rate of flow through a unit area under a hydraulic gradient of one. In dry ash disposal systems, bottom ash used as a filter or drainage blanket must have sufficient permeability to conduct water out of the fill and avoid the build-up of hydrostatic pressures. The permeability of fly ash governs the rate at which water passes through an ash fill, and affects the rate of leachate formation. In wet disposal systems, ash permeability, along with the hydraulic gradient, determines the dewaterability of the ash. For wet disposal sites, dewatering is a common means of stabilizing the ash for pond closure. Ash permeability is also an important consideration in wet/dry disposal systems where ash is placed in a dry fill after dewatering. Permeability may be analyzed by either constant head, falling head, or pressurized methods. ASTM D2434 describes a constant head method of permeability testing; however, when the permeability of the material is low, other methods may be required to provide sufficient volume of water to calculate a value for permeability. In this case, the pressurized method provides data in a relatively short time period, while other test methods may require a longer testing period.

Capillary Rise

Capillary rise is the physical phenomenon in which a liquid is drawn upward in a tube due to surface tension forces. The height of capillary rise is a function of the tube size and material properties. This same phenomenon will occur in soils and soil-like materials, such as fly ash. Capillary rise influences the stability of ash fills, and can influence leachate production.

Abrasion

Abrasion is an important ash property in the design of some ash handling and transport systems. These systems include vacuum and pressure handling systems, pressure transport systems, and slurry pipelines. Other systems affected by the degree of ash abrasion are ash transfer facilities and auxillary ash handling equipment, such as baghouses and precipitator hoppers. Analysis of ash abrasion must consider the proposed transport mode. Although no standardized abrasion testing is presently used, slurry pipelines may be analyzed by a water abrasion analysis (ANSI/ASTM G6-77) and pneumatic systems analyzed by an air/abrasion analysis (ASTM D658). Since these tests are non-standard relative to their applicability to transport systems, the results provide information comparable only to other tested materials. However, this data is applicable to the selection of ash handling equipment and materials. One limitation of this testing procedure is that, although it provides a basis for equipment selection, it provides no indication of life expectancy. Therefore, the life cycle cost cannot be estimated.

Temperature

The temperature of ash as it enters the in-plant collection and handling system plays an important part in the selection of materials and the design of handling system components. For example, it may be necessary to incorporate expansion joints in pneumatic fly ash handling systems near the particulate removal equipment hoppers, where fly ash is hot. Ash temperature, particularly fly ash temperature, also is important because it influences the air temperature, and thus the viscosity, of air used in pneumatic transport systems. At higher temperatures, the viscosity of air decreases. This has the effect of less solids handling capacity per unit of air.

Ash Chemical Properties

Ash chemical properties, while largely pertaining to the environmental aspects of ash disposal, may also affect the design of ash handling, storage, and transport systems. In addition, various ash utilization schemes, such as the use of fly ash in concrete, require that the ash have well defined chemical characteristics. Of particular interest in the design of ash disposal systems are the corrosive and self-hardening potentials of the ash produced.

Corrosion Potential

Ash with a high corrosion potential requires the use of corrosion resistant materials in the construction of ash handling and transport systems. Although the actual rate or degree of corrosion could be estimated by the potential, or electro-motive force (emf), of the ash and corrodable material, a common method of corrosion testing is by coupon testing. In this test, a coupon, or sample, of the material is imbedded in the ash under the assumed temperature and water content conditions. The sample weight loss, over a selected time period, is assumed to be the loss due to corrosion. The results are expressed as $mg/dm^2/day$ (MDD), and by assuming a uniform rate of corrosion, may be expressed in inches per year (IPY). Microscopic examination of the coupon should also be performed to assure the uniformity of corrosion.

Self-Hardening Potential

Fly ash with a potential for self-hardening, primarily the result of high free-lime content, requires special consideration of moisture content and ash transport time. In cases where highly reactive fly ash, i.e., rapidly self-hardening, is produced, slurry transport to the disposal area may not be feasible. Unfortunately, standard tests are not available to ascertain whether a fly ash is self-hardening or reactive. Various existing test methods may be utilized to determine these parameters. Since self-hardening ash involves the hydration of available free-lime with moisture, this sequence may be duplicated in the laboratory. If a series of unconfined compression cylinders are prepared with various moisture contents, both the presence and degree of self-hardening may be determined. Here, unconfined compressive strength would be utilized as the tested strength parameter. Testing performed on various ash samples for self-hardening are included in Table 3-1.

Reactivity

Reactive ash is defined as ash which exhibits rapid and uncontrolled hydration such that excessive temperatures are generated. These ashes have also been described as "Rapidly Self-Hardening"; although this describes the general process, it is not known whether the same reactions cause both effects. If fly ash samples are prepared with various water contents, and their temperature monitored, both the presence and degree of ash reactivity may be determined. These samples may also be tested for their unconfined compressive strength.

Pozzolanic Activity

Another area of interest is the use of fly ash as a pozzolan. Possible uses which exist in the concrete industry include the use of fly ash as a cement replacement and as a grout material. Specific tests required of the fly ash for use in cement concrete are defined by ANSI/ASTM C311-77. Specific chemical tests include:

Table 3-1

SELF HARDENING CAPACITY OF EASTERN ASHES (4)

	Chemical Composition (weight percent)								Self Hardening (psf)			Pozzolanic Index	
	Fe_2O_3	CaO	MgO	TiO_2	SiO_2	Al_2O_3	SO_3	LOI*	0 Day	7 Day	28 Day	Lime 7 (psi)	Concrete 28 (%)
Bituminous Coal Ash	4.77	.67	1.30	1.81	57.70	30.28	.23	1.76	464	552	743	470	96
	5.65	1.00	1.90	1.65	55.24	30.90	.29	1.09	2,134	1,994	2,287	835	94
	8.65	.92	1.58	1.54	56.39	27.69	.22	1.77	836	629	1,015	820	84
	7.64	3.19	2.62	1.42	54.94	26.21	.31	1.08	579	1,325	3,228	695	78
	12.70	1.15	1.20	1.29	53.40	26.30	.39	5.59	1,053	1,172	804	670	79
	35.10	3.08	1.33	.94	40.30	16.91	.33	4.06	555	517	718	325	72
	39.44	1.71	1.39	.69	43.18	11.86	.29	4.08	372	316	344	120	48
	20.51	4.11	2.00	1.42	47.72	20.19	2.16	16.66	1,200	1,053	1,430	990	100
	18.90	4.94	4.50	1.15	46.75	18.35	4.14	12.00	2,046	1,707	2,622	850	57
	16.54	1.98	1.30	1.54	48.48	27.47	.66	4.66	257	343	256	750 240	63 45
Anthracite Coal Ash	11.07	1.79	1.33	1.19	57.40	23.88	.39	11.72	402 1,409	572 1,686	1,114 2,110	605	56
	8.66	.65	1.41	2.09	55.33	28.13	.40	18.24	854	939	901	780	84

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*Loss on Ignition

Moisture Content
Loss on Ignition
Silicon Dioxide (SiO_2)
Aluminum Oxide (Al_2O_3)
Iron Oxide (Fe_2O_3)
Calcium Oxide (CaO)
Magnesium Oxide (MgO)
Sulfur Trioxide (SO_3)
Available Alkalies

Fly ash used in concrete must have chemical characteristics within limits specified by the American Concrete Institute (ACI).

Testing

Table 3-2 is a suggested list of chemical analyses to be performed on the ash to assess its potential for both environmental impact and utilization. These analyses are divided into a solids analysis and a leachate analysis. A solids analysis provides information pertaining to ash utilization potential, and also provides an indication of amelioration measures which may be required during site closure and revegetation. A leachate analysis of the ash provides information on leachate generation within ash disposal areas, which, in turn, provides an indication of the potential for groundwater pollution. Although applicable to estimating leachate strength, existing leachate analysis methods do not accurately predict leachate generation and must be used with great care. Presently, the proposed Resource Conservation and Recovery Act (RCRA) regulation includes a leachate analysis and extraction procedure that may become the standard method of testing in the future. Other methods have also been proposed and are described in the EPRI Coal Ash Disposal Manual (5).

PHYSICAL/ECONOMIC CONSIDERATIONS

Physical and economic considerations are primary factors in the selection of an ash system. Physical constraints of the site may preclude the construction of certain systems or subsystems. Once the appropriate site applicable systems are determined, then economic factors will determine the ranking of these systems. Environmental/ regulatory considerations, while important in the selection of overall ash disposal systems, have a more indirect effect on costs than do physical considerations. The physical/ economic considerations specifically to be reviewed include:

- Power plant size and configuration;
- Cost and availability of land; and
- Cost of money.

Power Plant Size and Configuration

Power plant size and configuration affect various aspects of the ash disposal system. The configuration of the power plant will affect the ash transport and storage systems by defining the layout and distance the ash must be transported. In addition, the area available for ash storage, treatment, and handling and transport facilities may also be defined. Other plant specifics to be considered are the number of boilers, the number and size of ash

Table 3-2

RECOMMENDED ASH ANALYSES

SOLID ANALYSIS
(REPORTED ON A DRY SOLID BASIS)

Water Content
Loss on Ignition (LOI)
Carbon (C)
Sulfur Trioxide (SO_3)
Phosphorus Pentoxide (P_2O_5)
Silica Oxide (SiO_2)
Iron Oxide (Fe_2O_3)
Aluminum Oxide (AlO)
Calcium Oxide (CaO)
Magnesium Oxide (MgO)
Sodium Oxide (Na_2O)
Potassium Oxide (K_2O)
Titanium Oxide (TiO_2)

Arsenic (As)
Boron (B)
Selenium (Se)
Cadmium (Cd)
Copper (Cu)
Zinc (Zn)
Chromium (Cr)
Mercury (Hg)
Beryllium (Be)
Tin (Sb)
Nickel (Ni)
Lead (Pb)

LEACHATE ANALYSIS

pH
Alkalinity
Acidity
Specific Conductivity
Oxidation Reduction Potential
Chemical Oxygen Demand
Sulfate (SO_4)
Phosphate (PO_4)
Silica (as Si)
Iron (Fe^{+2} and Fe^{+3})
Aluminum (Al)
Calcium (Ca)
Magnesium (Mg)
Sodium (Na)

Potassium (K)
Titanium (Ti)
Arsenic (As)
Boron (B)
Selenium (Se)
Cadmium (Cd)
Copper (Cu)
Zinc (Zn)
Chromium (Cr)
Mercury (Hg)
Beryllium (Be)
Tin (Sb)
Nickel (Ni)
Lead (Pb)

collection hoppers (both bottom ash and fly ash), the size and type of air pollution abatement equipment (electrostatic precipitators, fabric filters, or scrubbers), characteristics of the abatement equipment (including efficiency and location in the gas stream), and the distance and geometry from the ash hoppers to the storage, treatment, or transport area.

Cost and Availability of Land

The cost and availability of land is another consideration in the selection of an ash disposal system. Land is required for ash storage and transport systems at the plant, as well as for the ash disposal site. It is advisable to purchase all the land required for a power plant, including the ash disposal area, at the outset. If this is not done, the cost to acquire the land at a future date may be substantially more expensive. Inflation in land costs, particularly in the proximity of a power plant, can be greater than the general inflation rate. Due to current siting regulations, future power plants will most likely be located in rural areas where the cost of land should not be a major consideration. In the eastern portion of the U. S., power plants are often located in river valleys, due to the availability of cooling water. Many of these sites are restricted in the amount of land that is readily available near the plant. In this case, the location of available land in relationship to the plant has a major impact on ash disposal costs, particularly the cost of ash transport.

The land must be suitable for the use for which it is intended. Land designated for ash storage must be capable of supporting the required structures and truck traffic. Land considered for use as an ash disposal area should receive careful analysis since the land requirements for the disposal area are much larger than the plant facilities and often exceed the land requirements of the entire power plant. Specific land requirements for the disposal area include:

- Sufficient disposal volume for the life of the power plant;
- Proximity to the power plant;
- Access;
- Stability;
- Minimal surface and groundwater contact;
- Availability of a natural liner material; and
- Suitable material for embankment construction, if considered for wet disposal.

Additional siting criteria may also be established by the Resource Conservation and Recovery Act. These criteria may include:

- Exclusion of wetlands;
- Protection of endangered species; and
- Location above the 100 year floodplain.

Cost of Money

The cost of money combined with specific accounting methods has a significant impact on determining the total life cycle ash system cost. The magnitude of this economic consideration is substantial, as will be demonstrated in following chapters.

Another economic consideration in the analysis of ash systems is the method of accounting for overhead factors and their application to the ash system. These accounting procedures, which vary from utility to utility, may not include any overhead factors of the system, or may include a proportional share of company overhead. Although the accounting procedures may vary, each ash disposal system must be analyzed with respect to overhead factors. If these are ignored, then an operation intensive system may seem more economical than a comparable capital intensive option, since the overhead cost has not been included.

ENVIRONMENTAL/REGULATORY REQUIREMENTS

The final set of decision parameters to be reviewed are those pertaining to regulatory requirements. These regulations may exist on a local, state or federal level and are primarily concerned with minimizing environmental effects and maximizing public safety. Examples of regulations and required permits applicable to an ash system are:

- Solid waste disposal;
- Water quality;
- Air quality;
- Dam construction;
- Occupational Safety and Health Act (OSHA);
- Stream encroachment;
- Highway access; and
- Zoning.

Environmental regulations, solid waste, air and water, are based on the impact on the environment created by ash disposal. This impact can be negative or positive in nature. Major areas of environmental concern are:

- Water quality/aquatic ecology;
- Terrestrial ecology;
- Land use;
- Aesthetics;
- Public health/safety;
- Noise;
- Air quality; and
- Socio-economics.

Positive environmental impact is created by the reclamation of mined or devastated lands with ash. Negative environmental impact occurs through the displacement of terrestrial ecology, changes in land use, and other environmental changes which can be long-term, after site closure, or short term, during ash placement operations. Methods are available to reduce the degree of environmental impact by proper siting of the disposal facility (6).

Regulations influence ash system alternatives in several ways. The disposal area wastewater discharge is regulated by the National Pollutant Discharge Elimination System (NPDES), usually administered by the state. Other state regulations can control dam construction, stream encroachment, and highway access. Local regulations may pertain to solid waste disposal and land use.

The two federal laws which have the greatest impact on ash disposal are:

- The Clean Water Act of 1977 (CWA);
- The Resource Conservation and Recovery Act of 1976 (RCRA).

As previously mentioned, these regulations will include either specific information for the design and operation of ash disposal sites or provisions which will influence area design by specifying environmental quality standards such as surface and groundwater contamination levels.

An important design criteria, to be established for future ash disposal sites by CWA, is the discharge of suspended solids. Effluent regulations have been proposed for new power plants, which may require closed-loop slurry water systems for wet disposal. This is due to the regulations which may require a zero discharge of suspended solids from the ash pond. However, current litigation might alter this requirement. For the purpose of this report, it was assumed that a closed-loop slurry water system was required.

The siting and operation of an ash disposal system can have a major impact on surrounding communities, particularly when the disposal site is located near a community. These concerns are primarily health and safety. Aesthetics also enter into discussion of the impact of an operation or system. In the design of the ash disposal system, consideration should be given to public acceptance of the disposal operation. Possible specific areas of public concern are:

- Land use;
- Traffic;
- Noise;
- Dust; and
- Health and safety.

Should the use of a publicly sensitive disposal site be proposed, it may prove expedient to incorporate public comments into the selection process prior to the final site selection. Under certain circumstances, the National Environmental Protection Act (NEPA) may require that an environmental assessment be performed, and specific comments obtained from the public through a public participation program.

SECTION 4

OVERVIEW OF ASH DISPOSAL ALTERNATIVES

INTRODUCTION

Ash disposal systems have several major components including handling, storage, transport, treatment, and disposal. Within these major components exist various alternatives, as shown by Figure 4-1. The purpose of this section is to present an overview of ash disposal alternatives. Subsequent sections will provide more detailed descriptions of system components.

FLY ASH DISPOSAL

Fly ash is commonly collected dry from particulate removal systems and temporarily stored in ash hoppers. Upon filling these hoppers to a predetermined level, the fly ash is pneumatically conveyed to either a storage silo prior to dry transport, or to a mixing area where the ash is slurried for wet transport. Pneumatic fly ash handling systems can be vacuum, pressure, or a combination of vacuum and pressure. From storage or sluicing areas, ash is transported to either a wet or dry disposal area.

Dry Disposal

If the fly ash is to be utilized or disposed of in a dry system, it is transferred from the storage silo into the transport system. Transport of the dry fly ash is commonly done by truck, which may be open or closed, depending upon the destination of the fly ash. Belt and pneumatic conveyor, rail, or barge transport systems may also be feasible. Fly ash sent to utilization systems usually must be kept dry. Fly ash trucked to dry disposal sites is usually mixed with a small amount of water prior to loading in order to minimize dusting, and can be transported in open dump trucks. End-dump trucks are preferred due to the tendency of fly ash to clog bottom-dump openings.

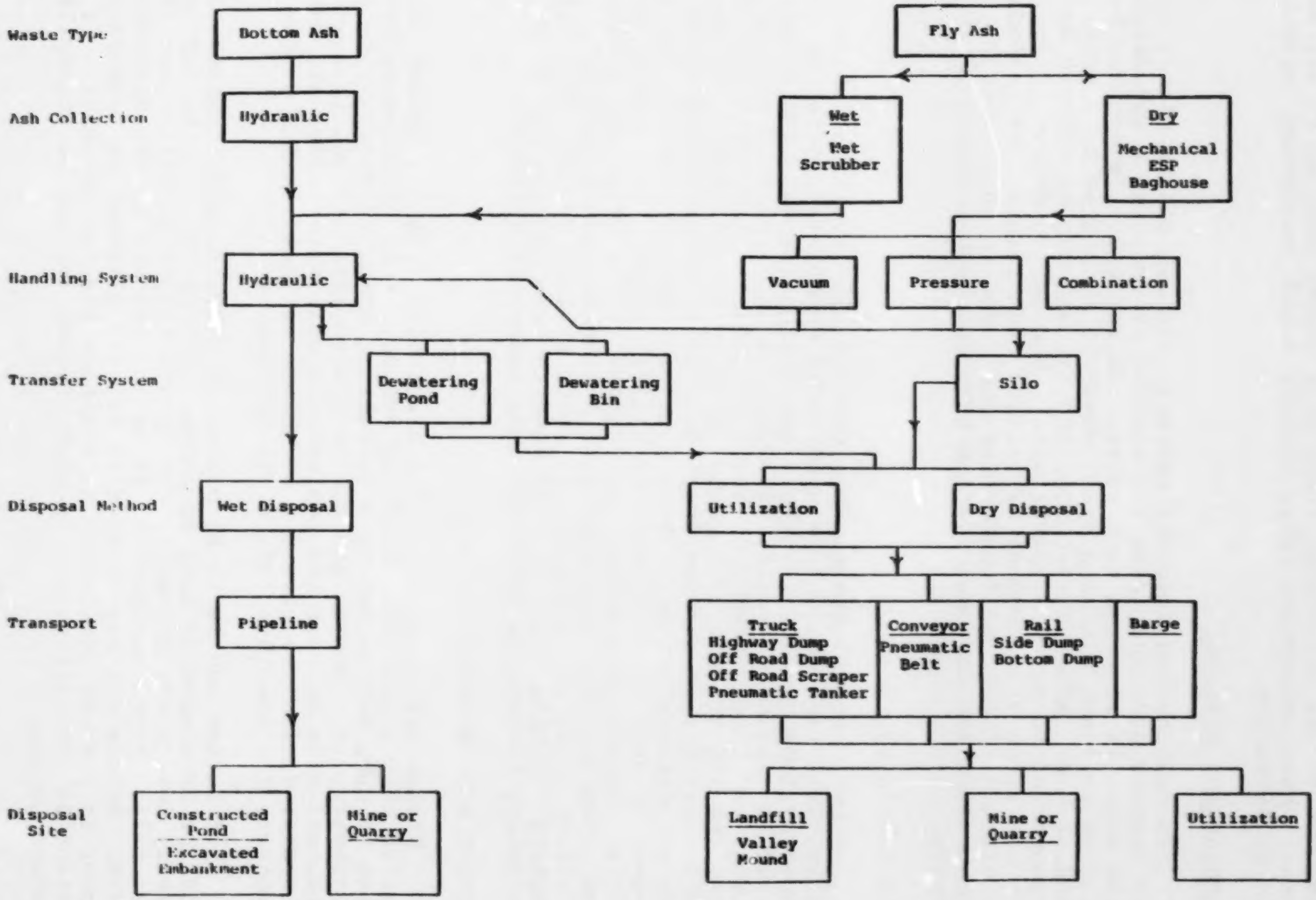
Dry fly ash disposal sites can be constructed landfills or located in devastated land areas. Constructed landfills can be located in the bottom of a valley (valley fill), on the slopes of a valley (side-hill fill), or on relatively flat areas (mounded fills).

Wet Disposal

If fly ash is placed into a wet disposal system, it is pneumatically conveyed to a sluicing area after collection from the particulate removal devices. At the sluicing area, fly ash is mixed with water to form a slurry of 5 to 10 percent solids, by weight. This slurry is usually pumped directly to the disposal area, although gravity transport systems have been used for short distances.

Figure 4-1

VARIATIONS IN ASH DISPOSAL SYSTEMS


Waste Type
Ash Collection
Handling System
Transfer System
Disposal Method
Transport
Disposal Site
Bottom Ash
Fly Ash
Hydraulic
Wet
Wet Scrubber
Dry
Mechanical
ESP
Baghouse
Hydraulic
Vacuum
Pressure
Combination
Dewatering Pond
Dewatering Bin
Silo
Wet Disposal
Utilization
Dry Disposal
Pipeline
Truck
Highway Dump
Off Road Dump
Off Road Scraper
Pneumatic Tanker
Conveyor
Pneumatic
Belt
Rail
Side Dump
Bottom Dump
Barge
Constructed Pond
Excavated Embankment
Mine or Quarry
Landfill
Valley
Mound
Mine or Quarry
Utilization

Wet disposal areas are usually ponds, although it may also be possible to use devastated lands in a manner similar to dry disposal. Pond embankment types include diked, excavated, side-hill, and cross-valley.

Combination Disposal

In combination disposal systems, fly ash can be placed in a dry storage area and later transported by truck to a wet disposal site where it is mixed with water. Conversely, fly ash can be sluiced to a wet sluicing area, where it is pumped to a holding pond or bin. After dewatering, the fly ash can be removed and transported to a dry disposal site. However, combination systems are not often used because of various constraints. For example, it is often difficult to dewater the ash. Due to these constraints, combination ash disposal systems have not been included in this report.

Fly Ash Fixation

Other disposal systems are commercially available which chemically treat fly ash to form a hardened material, similar to cement. These systems usually involve transporting fly ash from storage silos to treatment facilities, where it is mixed with various additives, and then slurried or trucked to disposal cells. Upon curing, the fly ash slurry hardens, forming a solid mass. Disposal cell construction and operation is similar in nature to those of dry ash disposal sites. These processes are proprietary and are generally only applicable to "reactive" ashes. These ashes presently compose only a small percentage of the total ash produced; therefore fixation processes will not be discussed further. If reactive ashes are encountered, which will be obvious from the ash physical testing, they must be handled with caution due to self-hardening tendencies which can make transport difficult.

BOTTOM ASH DISPOSAL

Bottom ash is commonly fed by gravity from the bottom of the boiler into a hydraulic handling system. This handling system is used to pump bottom ash to a dewatering area, or directly to a wet disposal site. Bottom ash can be placed with fly ash in a wet disposal site or have its own wet disposal site. Separate wet disposal facilities have the advantage of facilitating bottom ash recovery for possible future utilization.

If bottom ash is to be placed in a dry disposal system, it must be dewatered in bins or ponds. Bottom ash, unlike fly ash, is easily dewatered, primarily due to its larger particle size (Figure 3-1). After dewatering, it is transported to the disposal site. Bottom ash may be used in dry ash disposal as temporary cover to prevent dusting or as drainage blanket material. If the potential for utilization is high, bottom ash can be stockpiled for future salvage.

SUMMARY

Dry and wet transport and disposal of fly ash have been found to be viable ash disposal systems. Combination systems, i.e., wet transport and dry disposal or dry transport and wet disposal, are, in general, not cost effective as is evidenced by their lack of use within the industry. Also, specific fixation processes are not applicable to the majority of fly ashes and will not be discussed.

Bottom ash is typically transported hydraulically from the boiler to either a pond or a dewatering bin. Although transported wet, bottom ash is amenable to dry disposal or utilization due to its ease of dewatering. This property can play a significant part in an ash management program where bottom ash can be used as an aggregate replacement.

SECTION 5

ASH HANDLING SYSTEMS

INTRODUCTION

All coals contain a significant fraction of incombustible material or ash. The total ash quantity can vary from 6 to 50 percent of the coal on a weight basis. Thus, the quantities of ash produced are substantial and can approach the volume of coal consumed. This ash must be transported away from the boiler area to prevent the shutdown of the generating system. For the majority of utility coal fired power plants, the major sources of ash are:

- Fly ash from particulate removal systems;
- Ash deposited in the economizer and air heater hoppers; and
- Bottom ash from the boiler bottom.

This section will delineate major system components available to transport these ashes. General design information will be provided, but a specific system design is beyond the scope of this report.

GENERAL DESIGN CRITERIA

In developing preliminary designs for ash handling systems, there are a number of factors to consider. These include the following:

- Ash quantities, physical and chemical properties;
- Plant layout;
- Boiler design and configuration;
- Distribution of ash between fly ash, bottom ash, economizer ash, and air heater ash;
- Plant geographical location; and
- Type, configuration, and location in the exhaust gas stream of particulate removal devices.

Since ash handling is of critical importance in ensuring generating system operation, ash handling systems are typically designed to carry the daily maximum amount of ash produced in a 6 to 8 hour shift. This is to allow adequate time for maintenance on ash handling systems. The design of ash handling systems for 24-hour operation is also possible. Backup or duplicate systems can also be installed to provide an additional factor of safety in operation.

FLY ASH HANDLING SYSTEMS

Fly ash is commonly removed from the flue gas by either electrostatic precipitators or baghouses, and deposited into hoppers located directly beneath the collection equipment. From these hoppers, dry fly ash is either transported to an ash storage/transfer silo or to a mixing device, where water is added to form a slurry. An alternative method for fly ash collection is a wet scrubbing system. Fly ash is collected by a wet scrubber and absorbed by the water. These systems have the advantages of avoiding the use of pneumatic ash handling equipment and creating a slurry, which can be directly pumped to the disposal area. However, wet scrubbers have a limited use due to their high operation cost. In addition, scrubbers limit disposal options by requiring the use of a wet disposal system.

Pneumatic transport systems, utilizing positive pressure, negative pressure, or a combination of negative and positive pressures, are used for dry ash handling. Figures 5-1 and 5-2 describe both the collection hoppers and an ash transfer system. A brief description of these fly ash handling systems follows:

- Negative Pressure (Vacuum)
    1. Fly ash is transported from ash collection hoppers through a hydraulic vacuum producer to an air separation tank. The fly ash is then sluiced to a wet disposal area.
    2. Fly ash is transported from collection hoppers to a dry storage silo. Hydraulic or mechanical exhausters are used to create the vacuum. From the silo, fly ash is transported to a dry disposal area.
- Positive Pressure
    1. Fly ash is transported from collection hoppers to a dry storage silo or transfer station, and subsequently transported to a dry disposal area.
    2. Fly ash is transported from collection hoppers to a wetting device and subsequently sluiced to a wet disposal area.
- Combination
    1. Fly ash is transported from collection hoppers to a transfer station by a vacuum system. From the transfer station, fly ash is transported to a dry storage silo by a pressure system.

Table 5-1 lists typical design parameters for the available ash handling options.

Negative Pressure Systems

Negative pressure or vacuum ash handling systems, as shown on Figure 5-3, have the advantage of reduced fugitive emissions and are capable of accommodating a larger number of fly ash collection hoppers than positive pressure systems. However, the ash transport

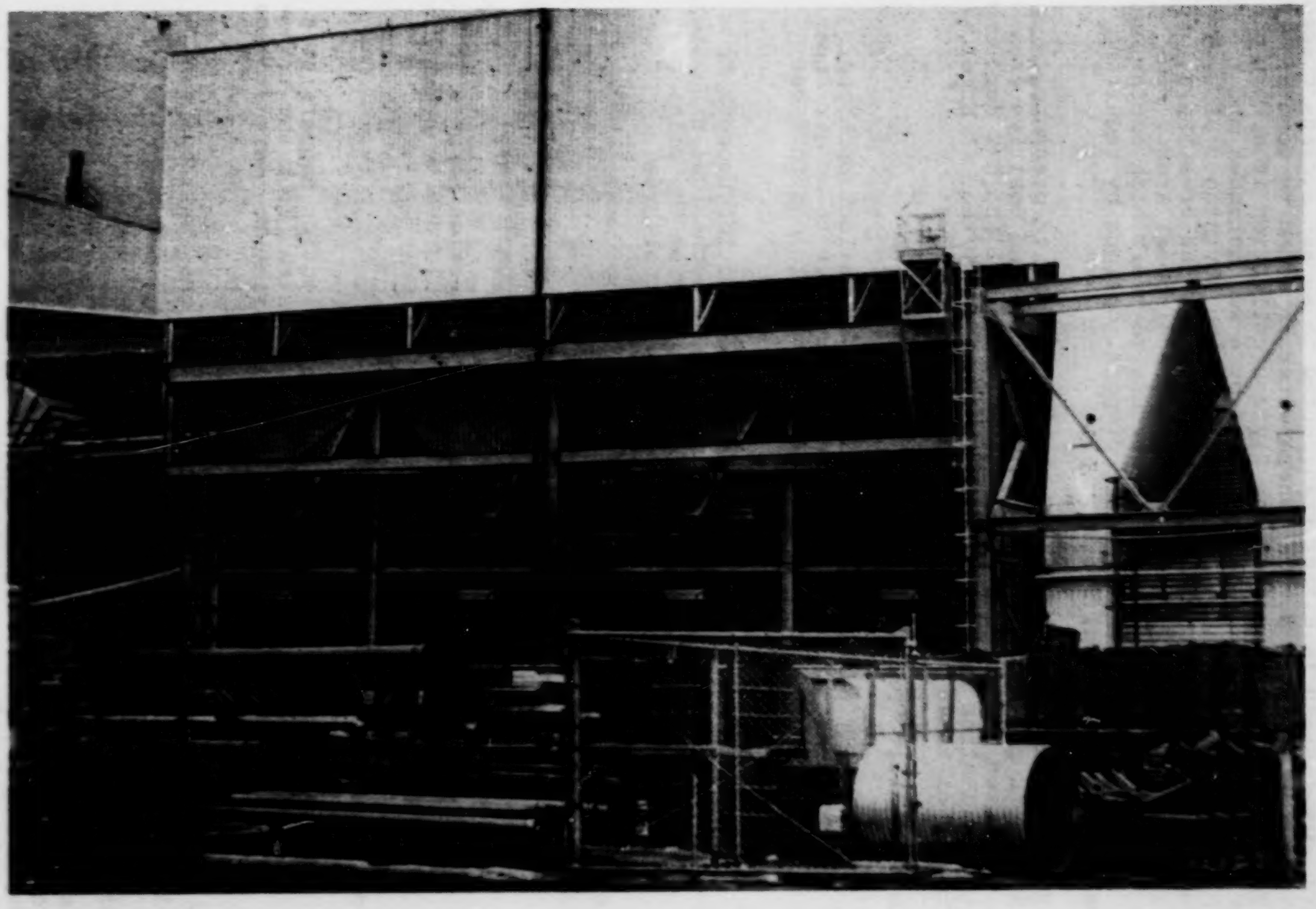


Figure 5-1

FLY ASH HOPPERS

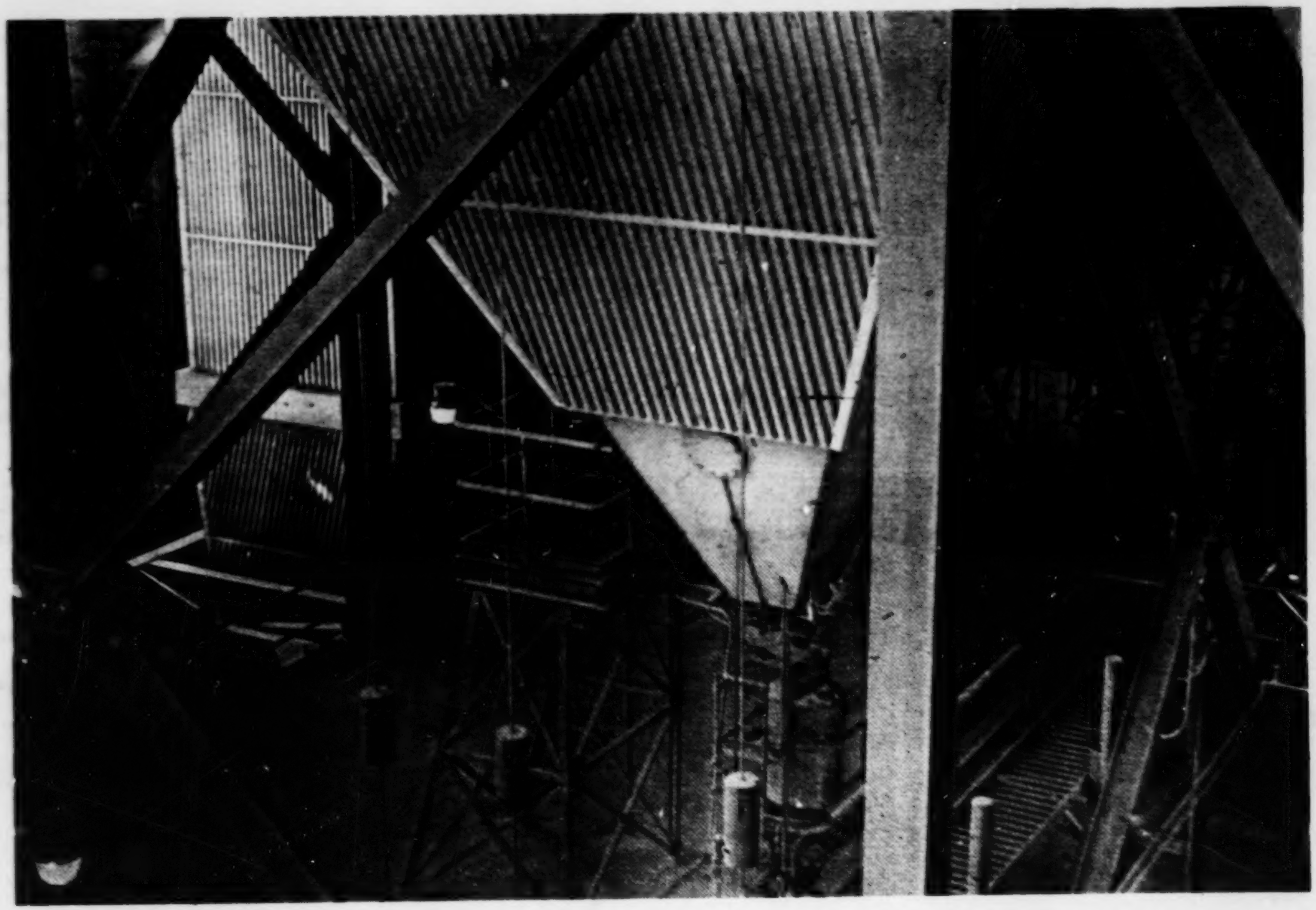


Figure 5-2

FLY ASH HOPPER AND TRANSFER SYSTEM

Table 5-1

CLASSIFICATION OF PNEUMATIC SYSTEMS FOR IN-PLANT ASH HANDLING (7)

		Transport Medium			
Parameter	Dilute Phase	Dilute Phase	Dense Phase	Dense Phase	Gravity Fluidized Conveyor
System Type	Fan	Blower	Pump	Blow tank	Airslide
Pressure Range	±20" H_2O	±7 psi	15 - 35 psi	40 - 125 psi	Fan type Closed: 1/2-1 psi Open: 4-5 psi
Saturation Capacity (ft^3 air/lb. material)	Vacuum 10 - 30 Pressure 4.5 - 13	Vacuum 3 - 5 Pressure 1 - 3.5	0.35 - 0.75	0.1 - 0.35	3 - 5 cfm/sq ft
Material Loading (lb. material/lb. air)	Vacuum 1.3 - .45 Pressure 3 - 1	Vacuum 4.5 - 2.5 Pressure 13 - 3.8	45 - 18	135 - 45	
Air Velocity (fpm)	6000	4000 - 8000	1500 - 3000	300 - 1000	10 thru diaphram
Maximum Capacity (TPH)	50	100	200	200	500
Practical Distance limits (ft)	Vacuum 100 Vacuum 200	Vacuum 100 Vacuum 1000	3000	8000	100 ft 6 ft drop/ length, 3° - 8° slope

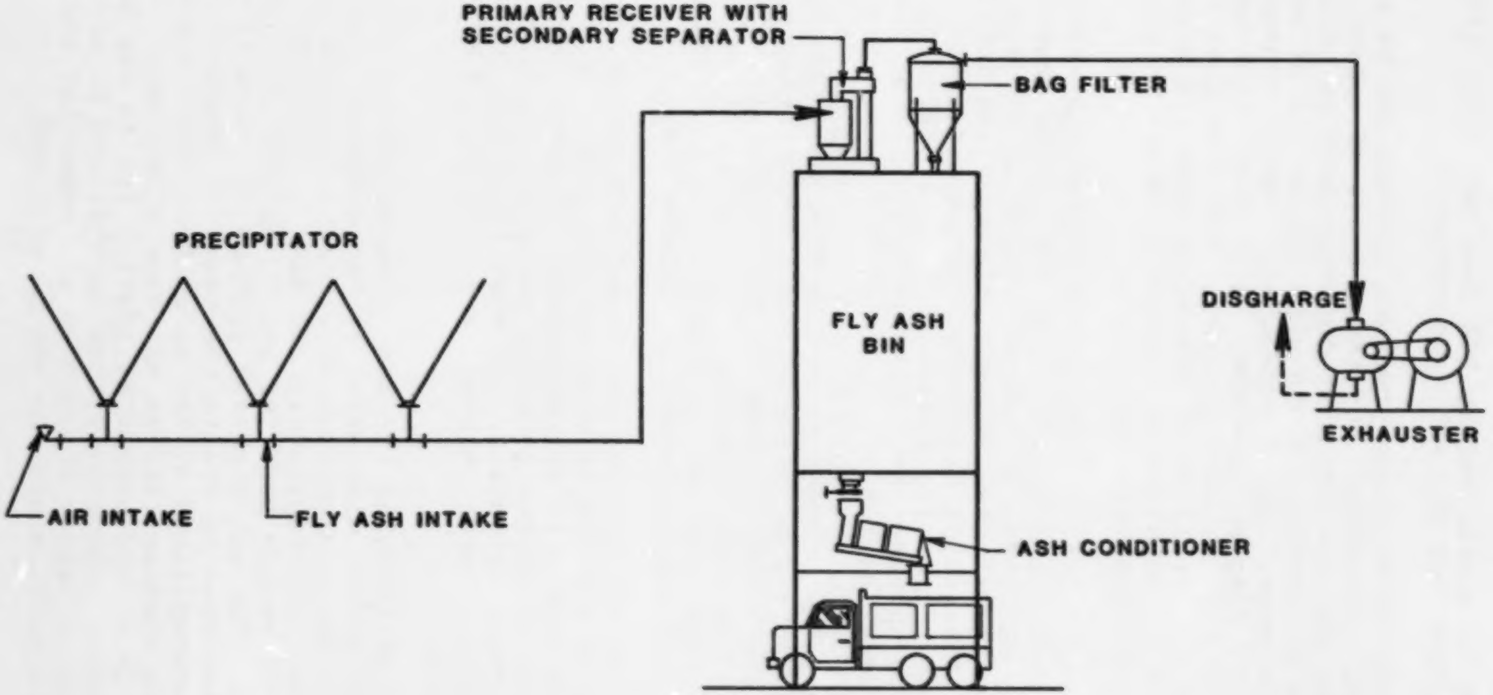

PRIMARY RECEIVER WITH
SECONDARY SEPARATOR
BAG FILTER
PRECIPITATOR
FLY ASH
BIN
DISGHARGE
EXHAUSTER
AIR INTAKE
FLY ASH INTAKE
ASH CONDITIONER

FIGURE 5.3 - NEGATIVE PRESSURE PNEUMATIC CONVEYOR

distance is limited to approximately 500 feet and their efficiency is affected by altitude and fly ash temperature.

Vacuum producers in negative pressure systems can be steam, water, or mechanical exhausters. Of these types of exhausters, water and mechanical devices are most commonly used in utility installations. Ash properties, along with the method of ash disposal, influence the selection of exhausters. Water exhausters can be used in wet or dry disposal systems, while mechanical exhausters are commonly used in dry disposal systems. Ash from coal having a high sulfur content is likely to be corrosive when mixed with water, and would have a substantial corrosive impact on water exhausters used in wet disposal systems.

A vacuum transport system operates by fluidizing the ash particle by a pressure differential. Fly ash passes from the particulate removal equipment to ash collection or storage hoppers. The fly ash is then transferred through intake valves into conveyance pipes. Intake valves are operated on a sequential basis directed by an automatic timing system. An alternative system approach would be to operate the intake valves by level controls in the ash hoppers. Here, as the ash level in the hopper increases past a preselected point, the intake valve would open. A control system would protect the conveyance system from being overloaded and phase in the appropriate intake valves. The primary maintenance point in this system is wear in the intake valves associated with the sliding gate mechanism. Conveying pipes are commonly manufactured from hard iron alloys which are designed to withstand abrasion and rapid changes in temperature.

Once the fly ash has entered the conveyance system, its movement is a function of the system size and geometry. In a vacuum system, the maximum length is approximately 500 feet. However, the length is a function of system geometry and plant layout. As in any material conveyance situation, the most efficient system is the most direct, therefore, bends, elbows, and tees should be used as infrequently as possible.

The method of discharging the ash is dependent on the final method of transport and/or disposal. If the disposal system is dry, the fly ash is carried through an air separator and dumped into a storage silo. Air separators are usually multistage, in order to protect the vacuum producer and to prevent fly ash from leaving the system. For wet disposal systems, fly ash is typically mixed with the water used to create the negative pressure in the system. This is accomplished at the exhauster, which ejects an ash, water, and air mixture into an air separating tank. From this tank, the fly ash is either pumped or gravity fed to the disposal area. If a mechanical exhaustor system is utilized to provide vacuum, the fly ash is passed through an air separator and dumped into a water filled tank, where the ash is slurried.

Positive Pressure Systems

While positive pressure systems are limited by the number of fly ash collection hoppers they can handle, they are capable of transporting fly ash for longer distances than negative pressure systems. The positive pressure system, as shown on Figure 5-4, utilizes a blower which is of a somewhat simpler design than a negative pressure exhauster.

Fly ash leaving the collection hoppers passes through an air lock/pressure feeder device, which prevents ash from blowing back into the collection device. These feeders are operated automatically in a predetermined sequence; however, the throughput of these feeders are less than a comparable vacuum intake valve. This reduced throughput is due to the operation of the feeder. The generalized feeder operation is as follows:

- An intake valve is opened and fly ash enters the feeder from the precipitator hopper under a slight vacuum.
- As the ash reaches a predetermined level or after a predetermined time interval has been exceeded, the upper intake valve is closed.
- The lower outlet valve is then opened and the feeder pressurized which results in the ash entering the pressurized system.
- After the ash has been exhausted, the lower outlet valve is closed and the feeder is ready for another ash transfer sequence.

Since the operation time of an air lock/pressure feeder is longer than a vacuum valve, the overall time for fly ash removal is longer. This time factor limits the number of ash hoppers that can be emptied during the ash handling operation period. Although the number of hoppers per pressurized line is limited, the problem can be resolved if more pressurized lines are added.

From pressure feeders, fly ash passes into conveying pipes of the same type as vacuum systems. If fly ash is being sent into dry disposal systems, it is conveyed to a storage silo. Air forced from the silo is vented through a fabric filter. If fly ash is being sent to wet disposal, it is conveyed to a slurry tank. The resulting slurry is sent to an air separating tank and subsequently pumped to the disposal area.

Pressure systems may be classified as either dilute or dense phase transport systems. This classification is based on the solids density of the transported material. Table 5-1 provides general design data for the available options. The majority of utility system fly ash transport systems are dilute phase. The design of a dilute phase transport system is based on the movement

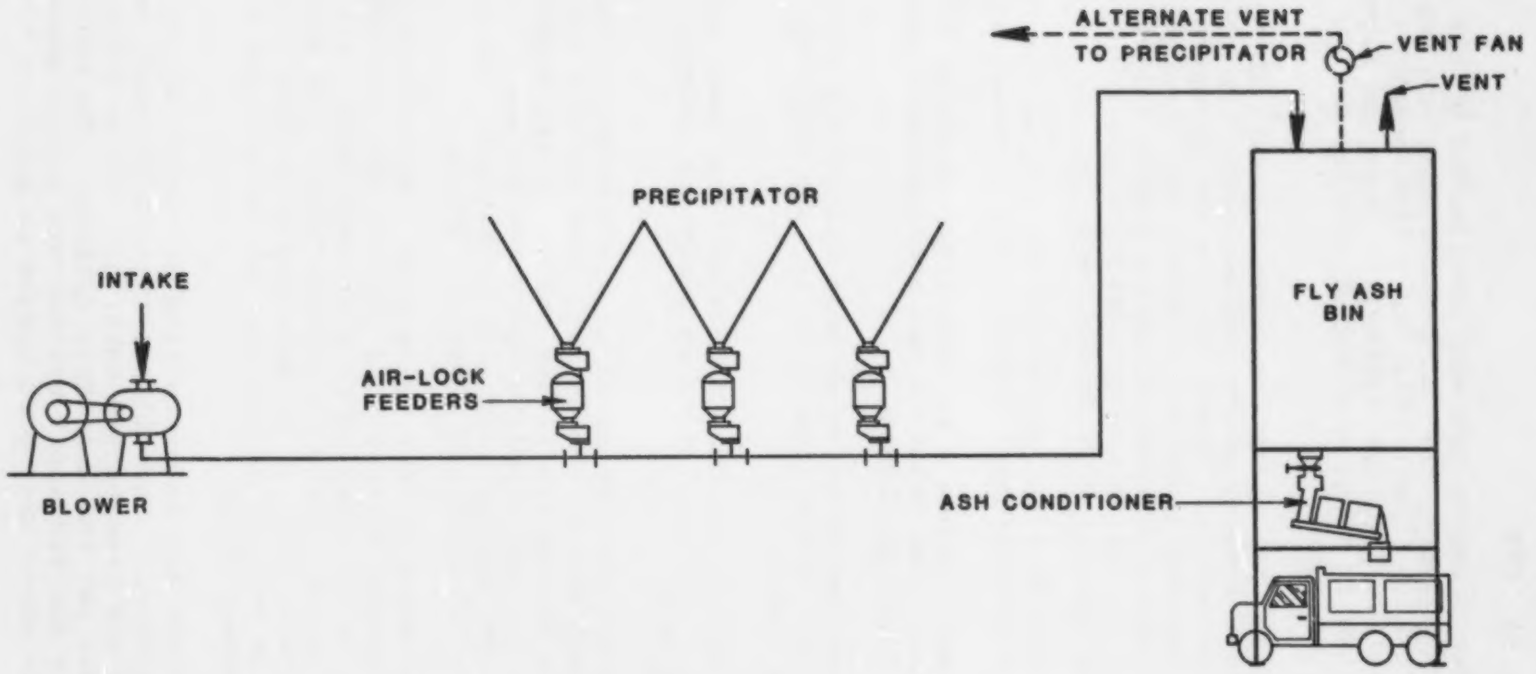

ALTERNATE VENT
TO PRECIPITATOR
VENT FAN
VENT
PRECIPITATOR
INTAKE
FLY ASH
BIN
AIR-LOCK
FEEDERS
BLOWER
ASH CONDITIONER

FIGURE 5.4 - POSITIVE PRESSURE PNEUMATIC CONVEYOR

of the largest probable particle and the bulk density of the material. This data provides the required average system velocity as described by Figure 5-5. The typical range of fly ash is shown on Figure 5-5. Bottom ash has not been included due to its large particle size, relative to dilute phase transport, and severe abrasion problems. To reduce abrasion problems and to provide increased design capabilities, a dense phase transport system may be utilized. As indicated above, this form of transport is similar to dilute phase transport except that higher pressures and lower velocities are used. Advantages of dense phase transport include the ability to transport denser or larger materials, reduced probability of plugging, reduced pipe size and reduced abrasion. The reduced abrasion may be described by the following equation (8):

$$\text{Abrasion} = (\text{velocity})^{a} (\text{density})^{b}$$

where: a and b are constants.

Studies on the abrasive characteristics of sand in pressure transport systems provided the following numbers for the above abrasion equation:

$a = 2.65$
$b = -0.37$

Due to the magnitude of the a and b constants, the equation indicates that to minimize abrasion one must minimize velocity and maximize density. This describes a dense phase transport system.

Combination Systems

In cases where a high rate of ash collection is desired, and fly ash must be conveyed over relatively long distance, combination vacuum pressure systems may be used. In these systems, fly ash is collected by a vacuum system and conveyed to a transfer station. Usually this transfer station has vacuum, equilizing, and pressure chambers, so that ash received from the vacuum system leaves the transfer station under pressure. The transfer station may be compared to a large air lock/pressure feeder device, described above for positive pressure systems. After passing into the pressurized conveyance lines, it may be transported to either a storage silo, ash slurry area, or the disposal area.

ECONOMIZER AND AIR HEATER ASH HANDLING SYSTEMS

Economizer and air heater ash can be handled by systems previously described for fly ash. It is necessary to either provide crushers or secondary hoppers, installed under each economizer and air heater hopper, to facilitate pneumatic transport, due to the tendency of this ash to sinter.

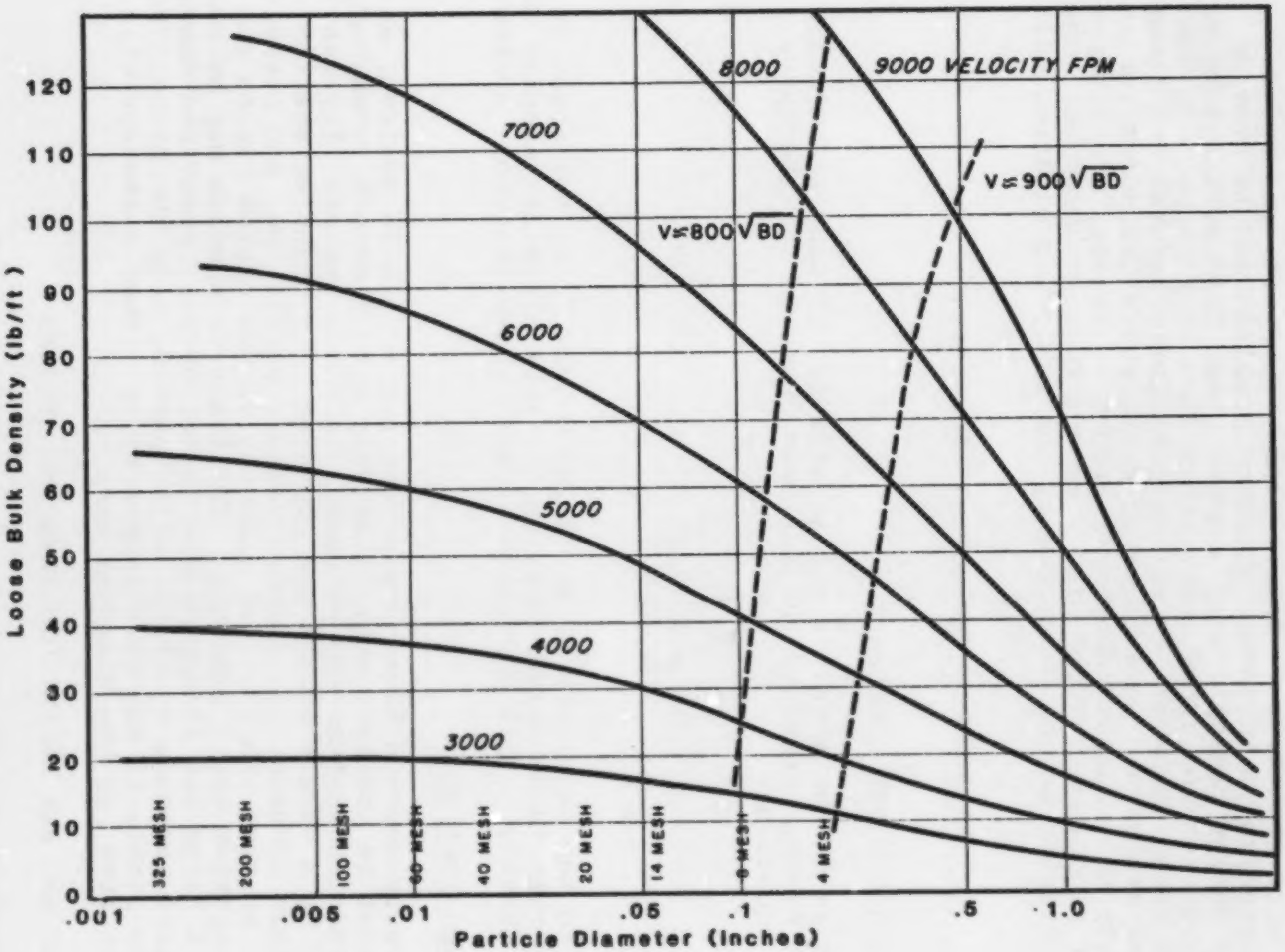


FIGURE 5.5 - APPROXIMATE AVERAGE AIR VELOCITIES IN DILUTE PHASE

With wet ash disposal, it is possible to collect economizer and air heater ash in water filled tanks, from which it is periodically pumped. Once wet, this ash is difficult to dewater. Therefore, hydraulic of handling economizer and air heater ash transport precludes the use of dry ash disposal.

BOTTOM ASH HANDLING SYSTEMS

Bottom ash is collected in hoppers located directly beneath the boilers. The description of a "wet" bottom boiler describes the physical state of the bottom ash within the boiler. Thus, the bottom ash from a wet bottom boiler is in a molten state when removed. Bottom ash from a dry bottom boiler is in a solid state when removed. In both cases, the bottom ash is typically dropped into a water filled hopper to shatter molten ash leaving the boiler, and reduce the ash temperature for future handling. There are a minimum of two bottom ash hoppers per boiler, depending upon boiler type and the ash melting temperature. Bottom ash hoppers are typically arranged in "V" or "W" configurations. Discharge from bottom ash hoppers is usually automatic, but manual discharge facilities are incorporated to provide a backup discharge system.

Bottom ash leaving the hoppers is usually passed through a clinker grinder for size reduction, then pumped to either a dewatering area (dry disposal) or directly to a wet disposal pond. Dry bottom ash transport is provided by at least one bottom ash equipment supplier. Bottom ash pumps can be jet or centrifugal types. Jet pumps cannot be air bound, require no sump pit, and are capable of handling overloads. They are limited by head and are subject to increased wear in closed-loop sluice water systems, where there is an increase in suspended solids. Centrifugal pumps can be placed in series for high head applications, and are relatively unaffected by the quality of recirculated water. Centrifigal pumps require a sump pit and must be oversized to account for loss of efficiency due to wear and to handle overloads.

Bottom ash sluice lines are constructed of durable materials, since bottom ash is an abrasive material. Commonly used pipes include hard iron alloy pipe, basalt lined steel pipe, and ceramic lined fiberglass pipe.

If bottom ash is sent to dry disposal or utilization, it is sluiced to a dewatering bin or pond. A minimum of two dewatering bins are required to provide bottom ash storage while one bin is dewatering. Bottom ash placed in dewatering bins can be loaded directly into ash transport vehicles. Bottom ash placed in ponds is excavated and then loaded into transport vehicles. In a closed-loop system, water from dewatering bins or ponds is passed through a clarifier prior to return to the sluice pumps. Usually the water return system also incorporates a surge tank to handle overloads. Figure 5-6 describes a typical bottom ash handling system.

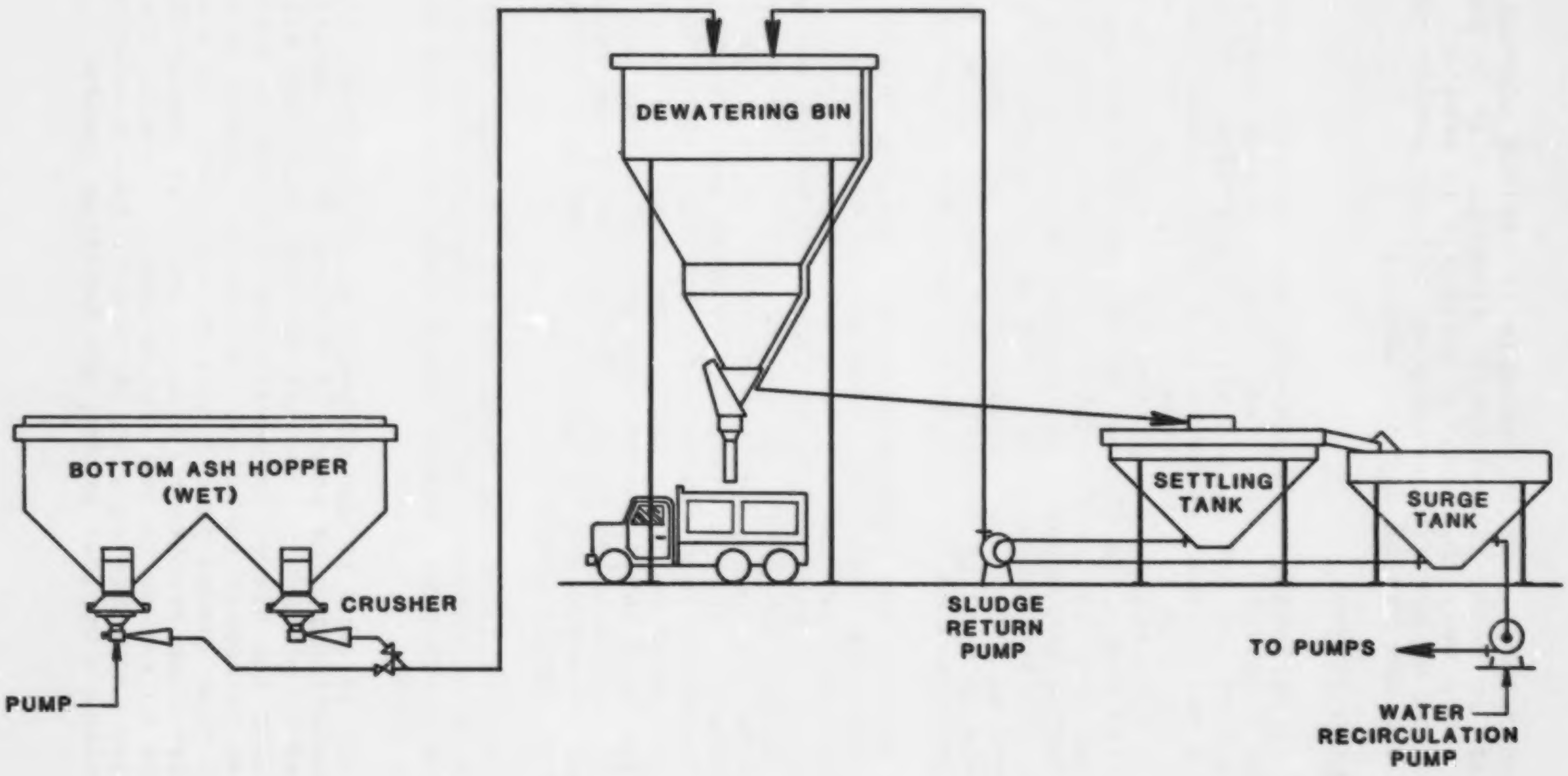

DEWATERING BIN
BOTTOM ASH HOPPER (WET)
CRUSHER
PUMP
SLUDGE RETURN PUMP
SETTLING TANK
SURGE TANK
TO PUMPS
WATER RECIRCULATION PUMP

FIGURE 5.6 – RECIRCULATING SLUICE CONVEYOR

OPERATIONAL CONSIDERATIONS

The primary difficulties in ash handling result from the abrasive nature of ash, and thermal expansion and contraction of ash conveying lines during surges in operation. Slide gates, valves, and elbows in ash transport lines are subject to wear and require continual inspection and maintenance. Ash slurry lines are sometimes rotated on a regular basis to increase life. Joints subject to expansion and contraction in fly ash pneumatic lines require inspection and maintenance to detect and correct leaks. Additional routine maintenance, including lubrication of moving parts and replacement of high wear components in pumps, is usually specified by equipment manufacturers.

In-Plant Handling System Cost

Table 5-2 is a summary of the in-plant handling system cost estimates made for this study. As can be seen, the variations in equipment costs and other considerations are quite broad. This range of costs is due to the general nature of the study and the importance of specific plant layouts in the actual types and amounts of equipment supplied. Due to the nature of these systems and their reliance on plant specific details, the costs used for this study could only be generalized. This is further described in Section 9.

Table 5-2

IN-PLANT HANDLING SYSTEM COST ESTIMATES

Manufacturer		Transport Phase	Units	300 MW Fly Ash Hoppers	Cost	Units	600 MW Fly Ash Hoppers	Cost	Units	900 MW Fly Ash Hoppers	Cost	Units	1300 MW Fly Ash Hoppers	Cost	Units	2600 MW Fly Ash Hoppers	Cost
Flakt	A,D	Dense (dry)		16	$ 463,000		32	$ 926,000		64	$1,389,000		80	$1,852,000		160	$ 3,704,000
United conveyor	A,C	Liquid	1	24	1,120,000	1	48	1,240,000	1	96	1,510,000	2		2,480,000	3		4,530,000
United conveyor	A,C	Dilute [pressure] (dry)	1	24	2,400,000	1	48	2,800,000	1	96	4,510,000	2		5,600,000	3		13,530,000
United conveyor	A	Dilute [vacuum] (dry)	1	24	1,975,000	2	48	3,450,000	3	72	4,775,000						
Allen-Sherman-Hoff	A	Dilute [vacuum] (dry)	1	40	2,386,750	1	40	2,386,750	2	80	4,773,500	2	80	4,773,500	4	160	9,547,000
Allen-Sherman-Hoff	A	Dilute [pressure] (dry)	1	40	2,616,250	1	40	2,616,250	2	80	5,232,500	2	80	5,232,500	4	160	10,465,000
Allen-Sherman-Hoff	A,E	Liquid	1	40	934,350	1	40	934,350	2	80	1,868,700	2	80	1,868,700	4	160	3,737,400

[A] Materials only.

[C] Includes ≅ 1 mile of piping to ash disposal area.

[D] Fly ash system only.

[E] Costs based on a per unit basis.

SECTION 6

ASH STORAGE AND TREATMENT SYSTEMS

INTRODUCTION

Various systems exist for the temporary storage or dewatering of the ash prior to utilization or disposal. These systems are dependent on ash properties, ultimate use, and other economic considerations. This section will describe the available systems and provide background on their relative merits.

FLY ASH STORAGE

Ash storage pertains primarily to dry fly ash. Bottom ash, although technically stored in dewatering bins or ponds, is covered in the following section. Wet fly ash is not commonly stored but is slurried to the disposal pond.

Dry fly ash storage silos, as shown on Figure 6-1, are situated at the transfer point between in-plant handling systems and out-of-plant transport. This interface is necessary since the capacity of the in-plant system is much larger than the out-of-plant system. Therefore, the ash storage silo must act as a surge chamber equalizing the plant output of ash with the out-of-plant transport system. Typically, a 72-hour storage capacity is used as a design factor, with the actual storage provided by one or more silos. The number of silos is also based, in part, on the number of boilers.

Fly ash storage silos are normally metal or concrete bins; however, other materials such as wood or plastics could also be utilized. These silos operate by accepting the fly ash from the in-plant system and exhausting the carrier air. To avoid an emission source, the carrier air is exhausted through a baghouse which then deposits the collected fly ash back into the silo. The stored ash may require agitation to assure a free flowing material during silo discharge. This is provided by air diffusers located at the base of the silo. Air is diffused through the ash such that the material becomes fluidized. This maintains the ash in an unagglomerated condition so that it may be easily removed.

Ash is normally removed from the silo by gravity and may be directed to several ash transport alternatives including trucks, railroad, conveyors, barges, or sluicing. The transfer from the silo to the out-of-plant ash transport system may include:

- o Mixing fly ash with water to provide a slurry for pumped transport (5-10 percent solids);
- o Mixing fly ash with water (10-20 percent) to reduce fugitive emissions for either truck, belt conveyor, or rail transport;

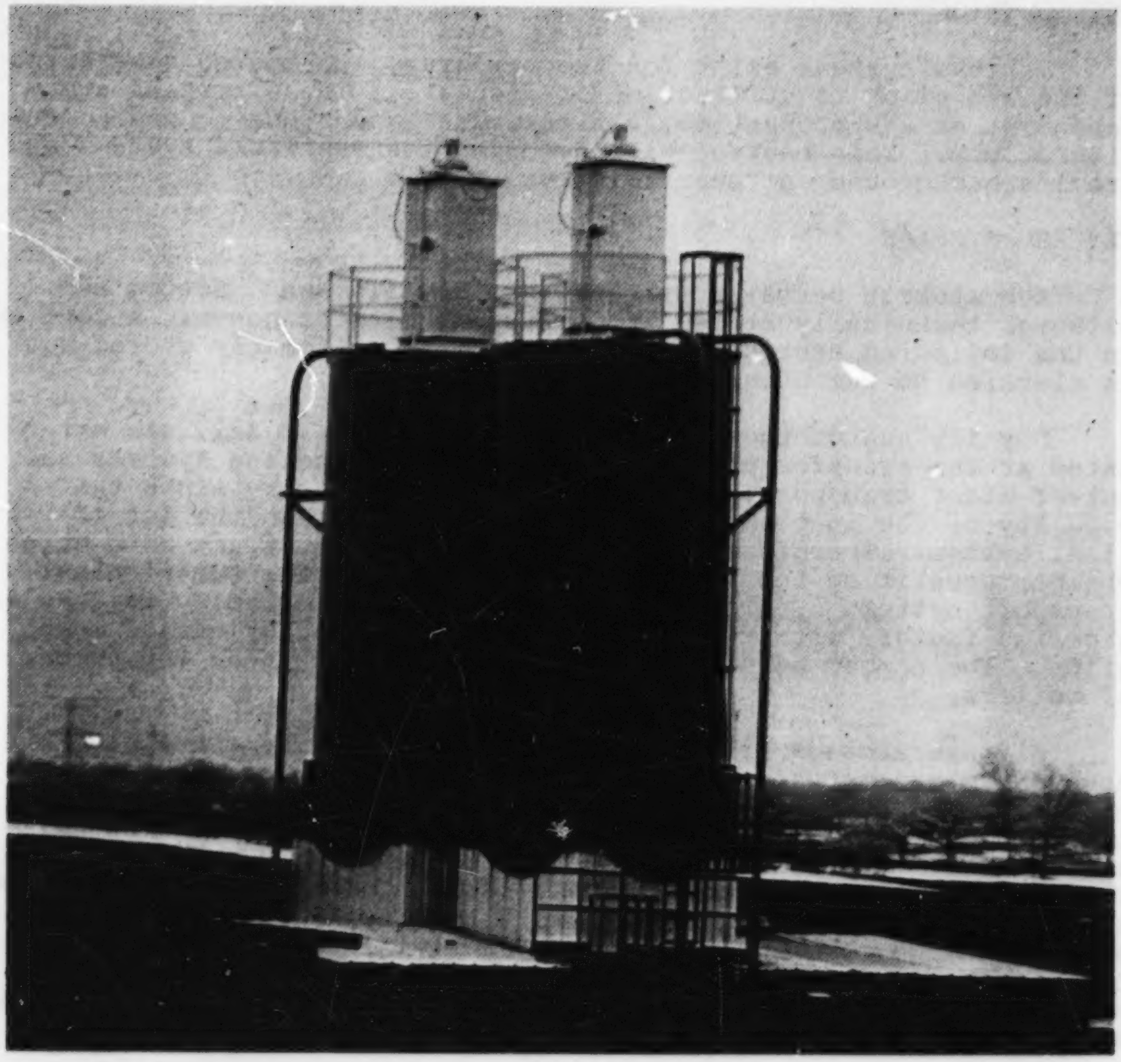


Figure 6-1

FLY ASH STORAGE SILOS

- Directly depositing fly ash into the transport vehicle for dry transport, normally for utilization;
- Direct transfer of fly ash to a pneumatic transport system.

Many power plants use more than one ash transport/transfer system since it is quite common to utilize a portion of the ash and dispose of the rest. This might involve slurrying a portion of the ash for wet disposal and transport of the rest in a dry state for utilization. This would require an in-plant ash transport system with two outlets. One would be to the slurry tanks for transport to a wet disposal area and the other would be to a storage silo for transfer to the out-of-plant transport system. This out-of-plant transport system would most likely be a dry system designed for a fly ash utilization scheme.

The physical requirements for the location of the ash silo are controlled by the plant layout, number and size of boilers, and the ultimate means of transport. Although small compared to the power plant, ash silos are quite large and, due to the congested situation at many power plants, may not be located near the boiler. Although this is not a problem for silo construction and operation, it may require a pressurized in-plant transport system if the silo is more than 500 feet from the ash hopper. The final requirement of silo location is the method of ultimate transport. The available options are listed in Section 8, however, each option has physical requirements. These requirements may dictate that the ash silo be elevated to provide truck clearance or allow the silo to be on-grade to facilitate pneumatic unloading.

BOTTOM ASH DEWATERING

Bottom ash is collected from the boiler bottom in either a liquid or solid state with the physical condition of the bottom ash supplying the boiler designation of "wet bottom" or "dry bottom". For either case, the ash is quite hot and, to reduce its temperature, is quenched in a water bath. This permits the rapid cooling or solidification of the ash so that it may be transported away from the boiler. After quenching, the bottom ash is typically sluiced to a disposal pond or dewatered. However, dry bottom ash transport systems, both belt and pneumatic conveyors, are currently being marketed. The rapid dewatering of the bottom ash is made possible by the large particle size of the bottom ash. The dewatering of bottom ash can be performed in either a dewatering pond or a dewatering bin.

Dewatering Pond

Bottom ash dewatering ponds are constructed so that as the bottom ash slurry enters the pond, the bottom ash settles out and the resultant liquid is removed. Once the pond is sufficiently full, the bottom ash is removed by dragline, backhoe, loader, etc. This removal operation requires that the pond be constructed such that the equipment can either reach all areas of the pond or that the equipment can enter the pond to remove the ash. The ash is loaded onto transport equipment and hauled to its ultimate destination.

Dewatering Bins

Bottom ash dewatering bins are large settling basins usually constructed of steel. A typical dewatering bin is shown in Figure 6-2. The bottom ash slurry enters the bin where the bottom ash begins to settle out due to the decreased water velocity. Once the bottom ash has settled out of solution, it is removed from the bottom of the bin by gravity, and placed into either trucks, rail cars, or conveyors for transport.

Depending on the settling velocity of the bottom ash particles, the available detention time, and the required effluent quality, dewatering bins operating in series may be required. By operating these bins in series, the discharge will have fewer suspended and settleable solids. In cases where the discharge must meet specific effluent requirements, the use of a series operated system can help to minimize additional effluent treatment.

If a water recirculation system is utilized for the bottom ash slurry water, a sluice water surge tank is necessary to accommodate system fluctuations.

Comparison of Dewatering Methods

The physical properties and principles relative to bottom ash dewatering are the same for both ponds and bins. However, each specific method has its own relative merits. Bottom ash ponds are readily constructed, do not require daily operation and are relatively impervious to breakdowns in the dry bottom ash transport preclude system. These ponds may require significant land area and careful design to preclude groundwater contamination, and are labor and equipment intensive in bottom ash removal. Bottom ash dewatering bins do not require significant land area and are amenable to the constant bottom ash removal necessary for ash utilization. Dewatering bins can be adversely affected by breakdowns in the dry bottom ash transport system if they do not have sufficient storage capacity.

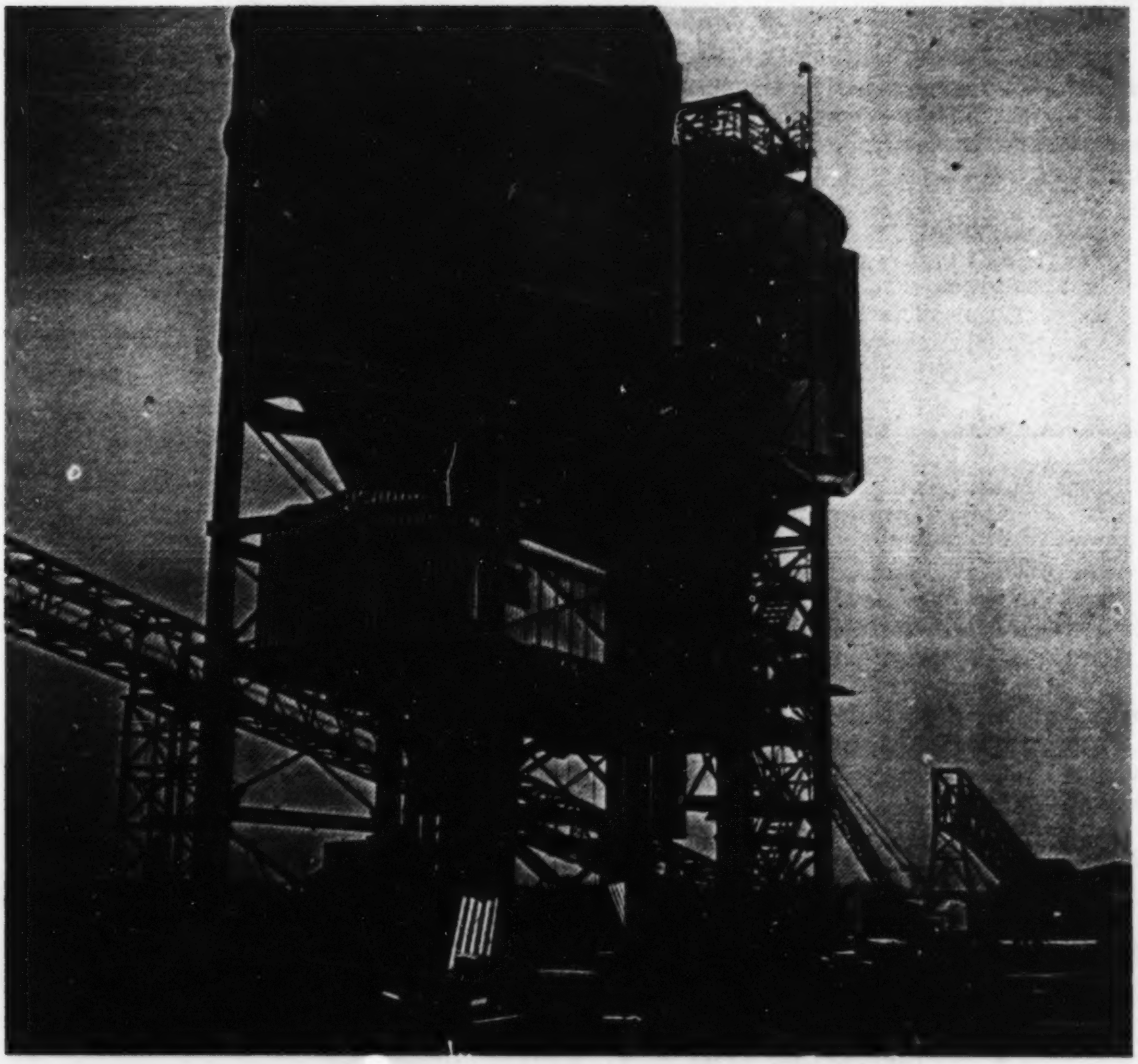


Figure 6-2
BOTTOM ASH DEWATERING BIN

SECTION 7

ASH TRANSPORT

INTRODUCTION

There are a number of methods available to transport the ash from the storage silo, dewatering bin, or slurry pump to the disposal area. These ash transport systems require a large capital expenditure and warrant careful design. The degree of variation in transport systems is typified by the following list of options:

- Truck
- Rail
- Barge
- Pipeline
- Belt Conveyor
- Pneumatic Conveyor

Each transport option also includes several alternatives.

An important consideration to be made in conjunction with the method of ash transport is whether the bottom ash and fly ash will be transported jointly or separately. Most transport systems can be designed for combined transport. Combined transport of the ash may preclude the use of the bottom ash. In the case of dry disposal areas, and to some extent wet sites, bottom ash may be used to provide underdrainage blankets, road bases or surfaces, temporary fly ash cover, or be otherwise used as an aggregate replacement. If bottom ash is transported with the fly ash, other materials must be obtained to serve the above purposes. However, these other materials are expensive when compared to the cost of bottom ash segregation.

TRUCK TRANSPORT

The transport of ash by truck is normally restricted to dry or lightly wetted ash. Commonly used methods of truck transport are:

- Highway trucks
    - Triaxle, dump truck, 25-ton capacity
    - Pneumatic trailers, 15-ton capacity
    - End dump trailer, 30-ton capacity

- Off-road trucks
    - Off-road dump truck, 35-ton capacity
    - Self-powered scraper, 30-ton capacity

This list represents a cross-section of available truck transport methods and commonly used sizes and types of equipment. Many other types and sizes of equipment are available.

Truck transport has the advantage of utilizing an existing technology that is capable of quickly reacting to changes in operating conditions. If breakdowns occur, additional equipment can be rented, or if the primary transportation route is made unusable, other routes are usually available. Truck transport places the ash at the point of active disposal operations and, therefore, does not require second handling. These advantages provide for flexible operation and the ability to meet future changes. Disadvantages of truck transport are primarily labor and operating costs. The reliability of truck transport is dependent on the truck drivers and the availability of fuel. In addition, since it is labor and energy intensive, its cost is directly related to these items. Unfortunately, the costs of labor and fuel are difficult to predict since recent increases have exceeded normal inflation rates. Thus, the future cost of truck transport may be difficult to accurately estimate.

Economic Comparison of Trucking Alternatives

To assess the most economical method of truck transport for the disposal system cost estimates, an analysis of truck transport options was performed. Pneumatic trailers were shown to be a cost effective means of transport primarily for ash utilization schemes requiring longer transport distances than these considered for this study and were not considered in this assessment of trucking costs. This analysis included:

- On-road 25-ton triaxle truck;
- On-road 39-cubic yard end dump trailer with tractor;
- Off-road 35-ton truck (Caterpillar 769C);
- Off-road 50-ton truck (Caterpillar 773);
- Self-powered scraper, 30-cubic yard (Caterpillar 631D); and
- Self-powered scraper, 40-cubic yard (Caterpillar 657B).

The on-road vehicles analyzed were a 25-ton triaxle diesel with heavy duty components and a 39-cubic yard end dump trailer with diesel tractor. The purchase cost of a 25-ton triaxle truck is approximately $65,000. A life span of ten years was assumed. The total purchase cost of the 39-cubic yard end dump trailer and diesel tractor is $57,600. A ten-year life expectancy for the tractor-trailer combination was assumed. The off-road vehicles included in the analysis consisted of two trucks and two scrapers. The purchase cost of a 35-ton Caterpillar 769C truck is $232,235. The purchase cost of a 50-ton Caterpillar 773 truck is $329,000. Both were assumed to have a 12-year life. A 21- to 31-cubic yard Caterpillar standard scraper 631D has an approximate purchase cost of $322,850 and an estimated life span of 8 years. The purchase cost of a 32- to 44-cubic yard Caterpillar tandem scraper 657B is $467,761. It also has an 8-year estimated life. All above estimated life expectancies were based on a good maintenance program as recommended by the manufacturer. All purchase costs were based on a January 1980 purchase.

In order to determine the most economical means of transport of the six vehicles compared, an analysis was performed to determine the total number of vehicles required and when they would need to be replaced. An inflation rate of 8.5 percent was used and all costs were expressed in 1980 dollars. The life of the power station was assumed to be 35 years and the disposal area was located one mile from the plant.

A 2600 MW plant was used for the analysis. This plant would produce an estimated 6,656 tons (8,217 cubic yards assuming a unit weight of 60 pcf) of ash per day. It was assumed that although ash would be generated 24 hours per day 7 days per week, it would only be hauled 8 hours per day 5 days per week. The number of trips required per day for each vehicle are as follows:

- 25-ton triaxle requires 267 trips;
- 39-cubic yard end dump trailer requires 211 trips;
- 769C requires 191 trips;
- 773 required 134 trips;
- 631D requires 266 trips; and
- 657B requires 187 trips.

It was assumed that one-half hour per shift would be required for refueling and maintenance. Therefore, 7-1/2 hours of hauling time would be available. Using the Caterpillar Performance Handbook, Edition 9 (9) and other available information, the total time to load, unload, and make a round trip was estimated for each vehicle. Table 7-1 describes the estimated round trip time, number of vehicles and total vehicle cost for the estimated 35-year plant life. This analysis indicates that the cost of the 39-cubic yard end dump trailer would be significantly less than the other alternates. The operation and maintenance costs of these vehicles must also be reviewed. Table 7-2 was developed to assess the economic impact of fuel, lubrication, personnel, and maintenance. This analysis indicates that the 25-ton triaxle, 39-cubic yard end dump trailer, and the 35 and 50-ton off road trucks have similar overall transportation costs. An important consideration in the selection of a truck transport method is the estimated fuel consumption. Due to the comparatively high inflation rate of diesel fuel relative to the estimated 8.5 percent rate of inflation, disparities in fuel consumption could alter future transportation economics. Again referring to Table 7-2, the 25-ton triaxle uses the least fuel. If the cost of fuel rises from the estimated $1 per gallon to $2 per gallon, in 1980 dollars, then the following present worth comparison is relevant:

25-ton triaxle	$16,534,000
39-yard trailer	$15,685,000
35-ton off-road	$19,741,000
50-ton off-road	$17,875,000

Due to the above analysis, the 25-ton triaxle and 39-cubic yard end dump trailer are the preferred method of transport. For purpose of this report, the 25-ton triaxle truck was selected due

Table 7-1

TRUCK TRANSPORT INFORMATION

Vehicle	Round Trip* (minutes)	Number of Vehicles Required**	Total Number of Vehicles Including Replacements***	Total Vehicle Costs (in 1980 dollars)
25-ton triaxle	13.5	8	32	$1,192,000
39-cubic yard end dump	14.0	7	28	$ 924,000
35-ton off-road truck (Cat. 769C)	14.2	7	21	$2,009,000
50-ton off-road truck (Cat. 773)	16.8	6	18	$2,440,000
30-yard scraper (Cat. 631D)	16.1	10	50	$10,136,000
40-yard scraper (Cat. 657B)	14.0	6	30	$8,811,000

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*Based on a round trip distance of 2 miles.
**Based on 6656 tons of ash and an 8-hour work day.
***Based on a 35-year power plant life.

Table 7-2

TOTAL COST COMPARISON
2600 MW PLANT

	Equipment					
	25-ton triaxle	End Dump Trailer	769C	773	631D	657B
Capital	$ 10,364,264	$ 8,036,294	$ 17,469,606	$ 21,213,120	$ 88,139,870	$ 76,620,828
Fuel**	$ 16,412,882	$ 19,319,112	$ 33,228,873	$ 28,267,792	$ 81,554,252	$101,101,680
Lube	$ 1,969,546	$ 2,069,905	$ 1,931,911	$ 2,718,057	$ 3,089,176	$ 3,663,104
Personnel	$ 88,767,557	$ 76,605,297	$ 75,033,215	$ 64,443,038	$119,123,030	$ 70,257,589
Maintenance	$ 9,847,729	$ 11,039,493	$ 10,767,185	$ 10,524,316	$ 48,343,548	$ 56,438,670
Total	$127,360,000	$117,070,000	$138,430,000	$127,170,000	$340,250,000	$308,080,000
Present Worth Total Cost*	$ 14,646,000	$ 13,463,000	$ 15,919,000	$ 14,625,000	$ 39,129,000	$ 35,429,000

Note: Assumptions utilized for the above analysis are described in Appendix A.

*Assumes 11 percent discount rate.

**The above estimates assume average fuel consumption and are only for purposes of comparison. Actual fuel usage utilized in the final cost estimates was 60 percent higher than average.

to greater availability and present use within the industry. However, the selection of a truck transport method for a specific site may determine that another truck transport option may provide the least cost.

RAIL TRANSPORT

The transport of ash by rail car is not common at present due to operational constraints, such as unloading facilities and scheduling. However, ash transport by rail could be increased using the unit train concept. Existing rail cars which could be utilized for dry ash transport include bottom dump, side dump, and pneumatic tank cars.

Rail transport is advantageous since the rail routes made necessary by coal transport to power stations already exist. The cost of new track construction would not be included with ash transport costs. Applicable rail transport costs would include fuel consumption on the return trip, additional track and bed maintenance, and the cost of dumping the ash on the return trip at the coal mine or disposal site. Train routes are usually not affected by outside influences and are essentially independent of weather. Disadvantages of rail transport include increased on-site ash storage capacity, difficulties in unloading cars, and double handling to place the ash in the disposal site.

Double handling of ash is required since railroad cars can only deposit ash at a central location or along a specific rail line. To place this ash in a disposal area requires that it be picked up, transported, and finally placed. This operation would require equipment operation in excess of that required for spreading and grading of ash transported by truck.

BARGE TRANSPORT

Barge transport of coal ash may be practical for a few cases, but it does not show the possibility of wide applicability. Barging will be limited to stations located on or very close to navigable waterways, stations which can consider ocean disposal, and/or stations requiring a long transport distance (greater than 100 miles, 161 kilometers). Barging theoretically can accommodate wet or dry sludges, and provide high system reliability at very low unit costs. However, the limited transportation routes and the special loading and unloading facilities make the overall economics unfavorable for all but a few selected cases. Disadvantages include increased plant site ash storage capacity, difficulties in unloading, and double handling to place the ash in the disposal site.

PIPELINE TRANSPORT

The transport of ash by pipeline requires the slurrying of ash (typically ten percent solids by weight) and pumping it to an ash disposal pond. This method of transport is most commonly used for wet disposal schemes; however, a well draining ash could be dewatered and later placed in a dry disposal site. The available options for pumping the ash have been described in Section 5. Pump design is consistent with standard pumping system design. The only specific requirement is that the minimum velocity be sufficient to maintain the ash in suspension. Conveying velocities range between 4.5 and 12.0 feet per second, depending on a number of factors including particle size, material density, and pipeline configuration. After the pipeline system has been designed, the type of pipe may be selected. Pipe selection is based on various parameters, including ash properties. However, life cycle cost, including pipe life and maintenance requirements, is the primary consideration for pipe selection (10). The types of pipe available for ash transport are:

- Steel
- Cast iron
- Hard iron alloy
- Basalt lined steel
- Ceramic lined fiberglass
- Plastic (PVC, ABS, etc.)
- Fiberglass

The requirements of a fly ash transport system are not as severe as a bottom ash or combined transport system, since fly ash is less abrasive than bottom ash. Standard utility practice tends to favor either steel or cast iron pipe with mechanical joints. As the pipe wears, it is rotated such that the pipe is more evenly worn. A single pipe can be rotated three times prior to replacement. Other procedures are enjoying increased popularity. These include the use of high quality abrasion resistant pipe, such as basalt lined steel pipe and ceramic lined fiberglass pipe. These pipes provide substantial increases in the life expectancy of the pipe, and thus may warrant their high initial capital cost. However, some fly ashes may coat the pipe and in time can reduce its capacity. In this case, provisions for periodic cleaning of the lines must be provided. Examples of this are periodic pumping of bottom ash, designed access points for hydraulic and mechanical cleaners, and back-up lines and pumps.

An integral part of the pipeline transport system is the overflow water return system. Based on currently proposed regulatory requirements for a new source, an ash pond discharge will be limited to a small concentration of suspended solids. The easiest method of compliance may be a water recycle system which would require a water return line from the ash pond to the plant and, if there is not sufficient head, a water-return pump. Since the suspended solids concentration in the recycled water would probably be low, other conventional pipeline materials, such as plastic and fiberglass pipe, could be used in the water-return pipeline. The possible accumulation of corrosive substances in the slurry water should be investigated prior to final pipe selection. In addition, the potential for dissolved solids accumulation must be recognized.

Mitigation methods can include measures for pipeline cleaning previously discussed, changes in disposal pond operation to enhance ash settling, and water treatment. In addition to water treatment for the closed loop water, water treatment may be required for periodic discharges due to excessive water accumulation within the system. This problem would only exist in those areas where precipitation exceeds evaporation. These discharges would require treatment to at least reduce total suspended solids, total dissolved solids, and control pH. Current technology to provide total dissolved solids concentrations less than 500 ppm include reverse osmosis, electrodialysis, and distillation techniques. Although this type of treatment may be required at some sites, it was considered site specific and not included in the economic analysis.

The advantage of a pipeline ash transport system is that is relatively independent of labor or energy problems. The primary disadvantage of a pipeline is continual maintenance, although this may be reduced by the use of abrasion resistant pipe.

CONVEYOR TRANSPORT

Conveyor transport includes both belt and pneumatic transport of ash. Although the design basis of these transport alternatives are not similar, they do share similarities in that they:

- Require a dedicated transport line;
- Have a high initial capital cost; and
- Require a storage silo at the disposal area.

Belt Conveyor Transport

The transport of ash by belt conveyor requires that the ash be dry, although partial wetting may be used to reduce dusting. Conveyor systems consist of one or more conveyor flights, each made up of a continuous belt supported by rollers and powered by a central motor drive. Each flight is separated by a transfer station where the ash is transferred from one flight to another. The length of a conveyor flight is constrained by both strength of conveyor belt and required horsepower of the motor drive. Conveyor flights in excess of ten miles have been constructed. Another restriction of conveyors is the geometry of the transport system. The maximum slope of the system is typically restricted to less than ten percent, and large curves or turns cannot be executed without a transfer station. The number of transfer stations should be minimized since both their capital and operation costs are quite high. A final requirement of ash conveyor systems is that fugitive emissions be minimized. This can be accomplished by either wetting the ash or enclosing the conveyor. Reduction of fugitive emissions by wetting would cause emission violations unless a great deal of moisture control over the entire length of the conveyor is exercised. Therefore, an enclosed conveyor system would be preferred.

Advantages of a belt conveyor system include a lack of dependence on either labor or energy. Disadvantages include its high capital cost, plant disruption in a case of failure (unless a back-up system is available), and the requirement of double handling at the site to place the ash in the fill.

Pneumatic Conveyor

Pneumatic ash transport requires that the ash be completely dry. Pneumatic ash transport consists of a pressurized pipeline system in which the ash is transported along a stream of air. The actual design of the transfer method may be either dense phase or dilute phase, referring to the concentration of ash particles within the air stream. Upon reaching the disposal area, the air velocity is reduced and the ash settles into a storage silo prior to placement in the landfill. The carrier air is exhausted through a baghouse with the removed ash redeposited into the silo. Design of this type of system is restricted by the ability of the carrier air to transport the ash. Specific transport distance capabilities are based on the type of phase transport, temperature of the air and/or ash, piping system resistance, and altitude. If long transfer distances are required, a transfer or booster station may be necessary.

Advantages of pneumatic transport include unattended operation, use of an existing technology relative to ash handling, and ability to conform to existing topography. Disadvantages include high capital cost and double handling of the ash at the disposal area.

SECTION 8

DISPOSAL AREA CONCEPTUAL DESIGN

INTRODUCTION

The design of ash disposal areas is an integral part of the cost estimating process incorporated in the selection of an ash disposal system. The design of an ash disposal area is influenced by several site specific factors including:

- Area topography and geometry;
- Area geological and soils characteristics; and
- Ash disposal regulations.

The objective of an ash disposal site design is to create a permanent, stable site with a minimum of environmental impact and post-closure maintenance. The following portions of this chapter discuss the major design features of both wet and dry disposal sites. These features are of a general nature, and could be substantially modified by additional ash disposal system criteria, such as the hazardous or non-hazardous RCRA classification of the ash produced.

DRY DISPOSAL AREA

Dry disposal areas are commonly designed and constructed with methods similar to those used for the design and construction of earth fills. The EPRI Fly Ash Structural Fill Manual (1) contains detailed information concerning the testing of ash to determine its physical properties along with design considerations which are somewhat unique to ash. The major factors in the design of dry disposal areas are:

- Fill configuration and construction;
- Erosion and sediment control; and
- Surface and ground-water protection.

Fill Configuration and Construction

The overall slope stability of the site is influenced by its configuration and the manner in which it is constructed. Figure 8-1 shows a cross-section through a dry ash fill. Although the stages or zones of the cross-section are not typical, the overall fill configuration is. This figure is used to indicate the possible extent of ash zoning which could occur in a difficult geotechnical situation. The simpliest variation of the ash fill would be where all the ash was placed in a similar manner irrespective of any material zoning. The major configuration and construction features that influence slope stability are:

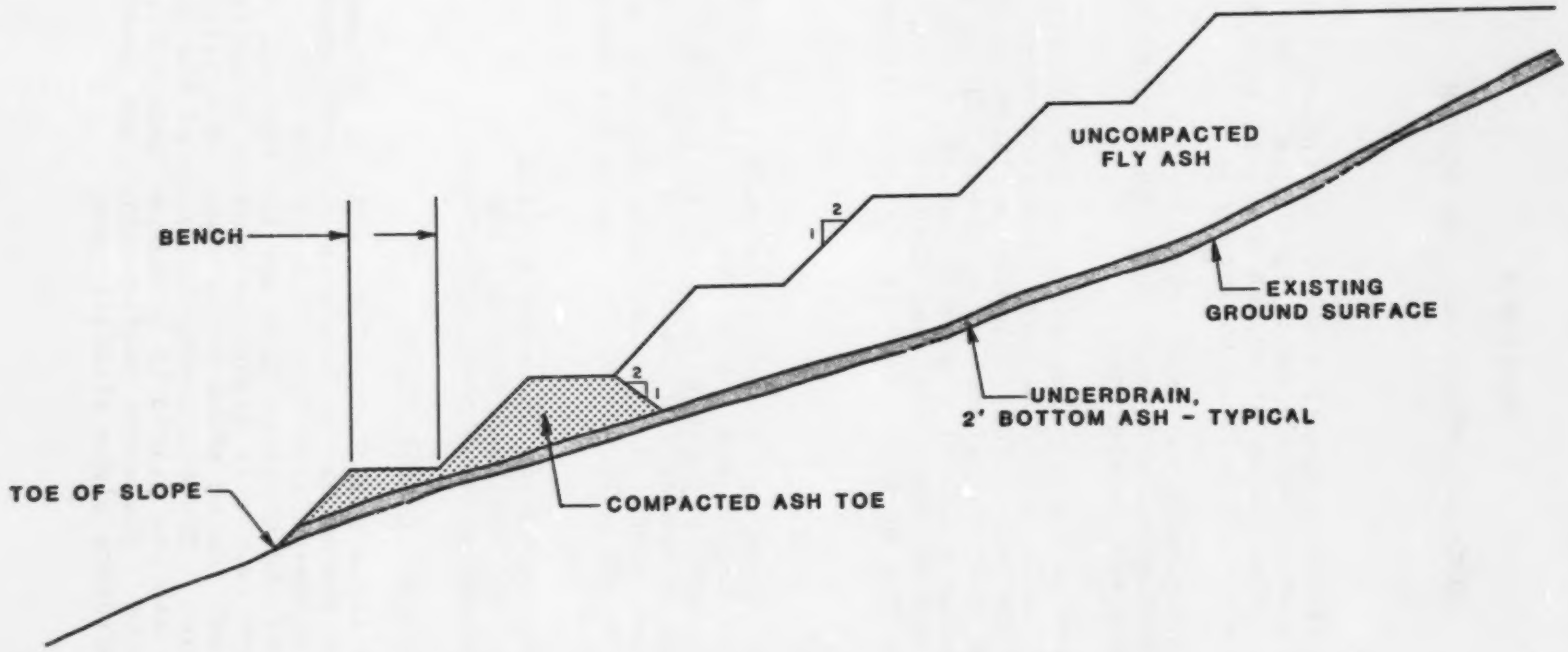

UNCOMPACTED
FLY ASH
2
1
BENCH
EXISTING
GROUND SURFACE
2
1
UNDERDRAIN,
2' BOTTOM ASH - TYPICAL
TOE OF SLOPE
COMPACTED ASH TOE

FIGURE 8.1 - CROSS-SECTION : DRY ASH DISPOSAL AREA

- Method of ash placement;
- Fill slopes; and
- Exclusion of water from the fill.

In dry ash disposal, ash is commonly hauled to the active portion of the fill, dumped, spread, and possibly compacted. The degree of compaction of the ash will influence the overall stability of the fill, the permeability of the ash, and also the volume required for ash disposal. For example, compacted ash will have a higher in-place density, higher shear strength, lower volume, and lower permeability than an ash loosely dumped without compaction.

Depending upon the method of ash placement and degree of compaction, fill slopes are designed to ensure the stability of the disposal area. Normally ash fills will be designed with overall slopes of 3 or 4 horizontal to 1 vertical, and incorporate terraces at 15 to 25 foot vertical intervals although material strength may dictate greater or lesser slope ratios. Local terrace slopes may be as steep as 2 horizontal to 1 vertical. It should be noted that the length and steepness of local slopes can influence other site features, such as soil cover and vegetation used in erosion control measures.

Water should be excluded from the fill in order to minimize the formation of leachate and ensure the fill integrity. The primary ways of excluding water are:

- Collection of groundwater with a layer of inert, permeable material placed beneath the fill. In some circumstances, the groundwater may require collection in a pipe underdrain network for discharge;

- Diversion of surface water away from the disposal area;

- Provision of positive drainage to the ash fill surface and provision of drainage systems to carry runoff away from the fill.

- Covering the ash with a soil material capable of supporting vegetation and providing minimal infiltration.

Erosion and Sediment Control

In order to satisfy environmental regulations and to prevent erosion, it is necessary to incorporate measures to control erosion and subsequent sediment transport from the fill. These design features commonly include:

- Staged site development in order to minimize the area of ash exposed without soil and vegetal cover;

- Sedimentation pond to trap sediment carried by site runoff;

- Ditches for channeling and controlling the surface runoff in the disposal site;
- Manipulation of the slope, length, and gradient in order to control runoff velocity and sediment transport potential;
- Berms at the foward edge of benches to keep runoff from flowing over the bench face;
- Sloped benches to direct runoff into collection ditches;
- Temporary sediment traps, such as straw bale barriers or sandbags, to trap sediment eroded from exposed ash or earth stockpiles;
- Soil cover and vegetation, if needed, on all exposed ash surfaces and soil stockpiles.

Surface and Ground-Water Protection

Increasing concern about the pollution of surface and ground waters has necessitated the use of water protection measures in the design of ash disposal areas. The use of these protection measures is determined by regulatory requirements, the type and permeability of soils underlying the site, and ash leachate characteristics. Commonly used site features intended to protect surface and groundwater are:

- A site liner - either natural or synthetic;
- Surface water diversion ditches and pipes;
- A permeable layer of inert material beneath the site to collect leachate; and
- Treatment of site leachate, if needed.

Although the above design features are commonly used at an ash disposal site, the actual selection of specific features must be performed on a site specific basis. For example, if a liner is required at a site to protect the groundwater system, a choice exists between a synthetic or clay liner. If clay is present at the site, the cost of its placement may be less than the cost of a synthetic liner. However, if the clay must be imported for any distance, it may become more expensive than a synthetic liner.

WET DISPOSAL AREA

The design of a wet ash disposal area incorporates the following major features:

- Embankment design;
- Surface and ground-water protection; and
- Required settling time.

In addition to these design features, consideration should be given to the post-closure requirements of a wet disposal area. If the disposal area is filled with ash and the power plant discharge is stopped, then the site is a landfill which should meet the design requirements previously discussed for dry disposal sites. If water continues to enter the site, then continuing maintenance of the embankment and discharge structures is required in order to ensure their integrity.

Embankment Design

The design of earth embankments is a detailed topic beyond the scope of this report. The height and type of embankment are influenced by the soil types and quantities available near the site along with the site topography and the required disposal volume.

Surface and Ground-Water Protection

The protection of groundwater, if required, entails the use of a site liner. This liner may be constructed of natural or synthetic materials. Surface water protection is somewhat more complex to analyze. It is possible that effluent restrictions will preclude pond discharge to surface waters and require the use of a closed loop water recirculation system. If a closed loop water recirculation system is to be used, it is necessary to undertake a water flow mass balance study to compare water entering the disposal area from sluicing operations, precipitation, and upland runoff with water leaving the area by evaporation and discharge. This type of study is necessary to determine the net amount of water returned to the plant, and the need for upland runoff diversion ditches. After closure, diversion structures should be constructed to direct runoff away from the site and prevent the erosion of ash surfaces.

Required Area for Settling

One of the primary functions of a wet disposal area is to provide sufficient detention time of the incoming ash slurry to allow the settling of ash particles. The settling of solids is theoretically related to the pond outflow rate, the surface area of the pond, and the critical settling velocity of the ash particles in the pond influent. This relationship can be stated as:

$$\text{Required Settling Area} = \frac{\text{Outflow Rate}}{\begin{array}{l}\text{critical settling velocity of} \\ \text{the smallest particle to be} \\ \text{retained}\end{array}}$$

Other design features, such as baffles or skimmers, may be required for cenosphere removal and to prevent short circuiting. It may also be necessary to incorporate underflow weirs, trash racks, or anti-vortex plates on discharge structures in order to prevent the outflow of particles and ensure the proper functioning of the discharge structure.

SUMMARY

Both wet and dry ash disposal systems must be constructed under a similar set of criteria. These include:

- Geotechnical stability of the fill or embankment;
- Protection of ground-water; and
- Protection of surface water.

The protection of surface and ground-water is typically regulated. However, various options must be examined to provide a cost effective system. These options include clay versus synthetic liners, depth and type of underdrain system, and other water quality control techniques. Regulations specifically pertaining to fill or embankment stability are not common and, therefore, provide an even wider range of design options to provide a cost effective system.

SECTION 9

ECONOMIC ANALYSIS

INTRODUCTION

The overall purpose of this report is to compare the relative costs of wet and dry methods of ash disposal for five power plant sizes ranging from 300 to 2600 MW generating capacity. The five power plant sizes, the number of units, and the ash quantities are as follows:

Plant Power Size	Units	Ash Quantity (tons/year)
300 MW	1	200,229
600 MW	2	400,457
900 MW	2	600,686
1300 MW	3	867,657
2600 MW	4	1,735,314

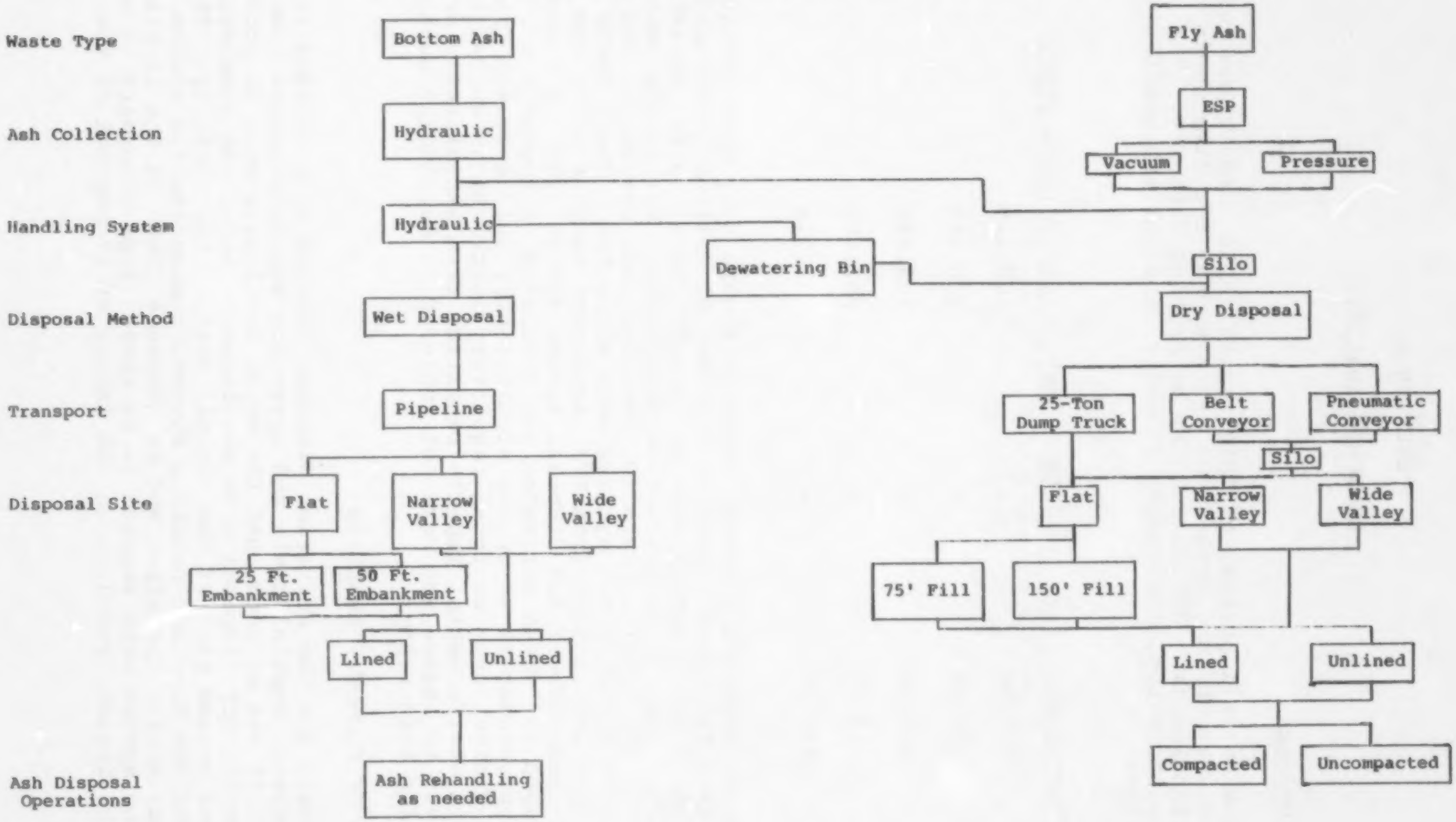
Conceptual disposal schemes, shown in Figure 9-1, were developed. These disposal schemes include a number of options within major segments of the disposal process in order to allow for variable conditions such as disposal site topography. Due to the general nature of the report, costs for construction, operation, and maintenance of ash disposal systems were estimated. These costs were based upon information from TVA, equipment manufacturers and suppliers, and current ash disposal system design practice. Assumptions used for these estimates are tabulated in Appendix A. Some decision parameters which can significantly influence ash disposal system design, such as local regulatory restrictions and site specific environmental impacts resulting from ash disosal, are difficult to assume and were not included in developing cost estimates for this report.

METHOD OF ECONOMIC ANALYSIS

Costs for the different disposal schemes were divided into two categories: capital costs and operation and maintenance (O&M) costs. It was assumed that the major facilities such as pond embankment, dry disposal site development, etc., was completed in 1980 and became part of the capital cost of the facility. This included the in-plant handling system, transportation system, and disposal area. Operation and maintenance items of the in-plant handling system were assumed to be those items necessary to maintain the system (based on an O&M factor of 17 percent of the capital

FIGURE 9-1

SPECIFIC ASH DISPOSAL SCHEMES CONSIDERED FOR COST ESTIMATING


Waste Type
Ash Collection
Handling System
Disposal Method
Transport
Disposal Site
Ash Disposal Operations
Bottom Ash
Hydraulic
Hydraulic
Wet Disposal
Pipeline
Flat
Narrow Valley
Wide Valley
25 Ft. Embankment
50 Ft. Embankment
Lined
Unlined
Ash Rehandling as needed
Dewatering Bin
Fly Ash
ESP
Vacuum
Pressure
Silo
Dry Disposal
25-Ton Dump Truck
Belt Conveyor
Pneumatic Conveyor
Silo
Flat
Narrow Valley
Wide Valley
75' Fill
150' Fill
Lined
Unlined
Compacted
Uncompacted

cost per year), maintenance and/or operation of the transportation system including required equipment replacements and the operation and/or maintenance of the disposal area which included ash placement/regrading or ash redistribution. The 17 percent O&M figure represents the upper limit on O&M costs, as indicated by Barrier (9). Lower rates, 5 and 10 percent, may better reflect actual utility costs and are included to illustrate the effect of O&M costs on the total system cost. The 5 and 10 percent rates may be more indicative of utilities that perform the minimum of O&M on ash disposal systems. To provide for the time value of money, an 11 percent discount rate and an 8.5 percent inflation rate were utilized.

The economic analysis of the disposal system cost was performed using two methods. The first was a present worth analysis of each alternative. The present worth of each alternative was determined by adding the capital cost of the project to the present worth value of operation and maintenance (O&M). Present worth O&M was determined by calculating the 35-year cost of O&M, utilizing an 8.5 percent inflation rate, and then discounting this amount at 11 percent to its present worth in 1980 dollars. The second method of analysis was a total system cost approach. This approach utilized a weighted cost of capital which combined the inflation rate with the cost of capital. O&M costs were inflated at 8.5 percent over the 35 year life of the plant to provide a total O&M cost. The total system cost, thus, becomes the summation of the weighted cost of capital plus the total O&M cost. The following equation was utilized in the determination of the weighted cost of capital:

$$(1 + r) = (1 + x)\ (1 + i)$$

or

$$r = [(1 + x)\ (1 + i)] - 1$$

where:

r = discount rate (weighted cost of capital in the presence of inflation)

x = cost of capital in the absence of inflation

i = Inflation rate (8.5 percent)

This equation results in the following factors for the two analyses:

Table 9-1

ASH DISPOSAL SYSTEM
PRESENT WORTH COST
(ALL COSTS IN MILLION $)

	300 MW		600 MW		900 MW		1300 MW		2600 MW	
Disposal Method	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner
PIPELINE										
Wet										
25'	32.6	21.7	57.5	36.3	81.7	50.2	112.3	67.0	222.5	132.6·
50'	39.5	33.7	59.1	48.6	78.0	62.8	101.6	80.1	189.0	147.1
N	17.7*	15.6·	35.2*	28.3·	50.0*	40.6·	68.0*	56.1·	133.2*	116.2*
W	20.5·	15.3*	36.0·	27.4*	50.5·	39.9*	68.2·	55.4*	138.0·	119.9·
TRUCK TRANSPORT										
Dry-UC										
75'	28.2	25.3	46.3	41.3	68.2	61.0	92.7	82.6	192.2	172.8
150'	27.2	24.5	42.1	38.1	60.4	55.3	80.3	73.5	164.9	152.7
N	28.9	25.8	46.9	41.7	67.6	60.5	89.5	80.3	171.9	157.9
W	30.2	26.7	53.5	46.5	73.6	64.9	94.2	83.7	173.8	159.3
Dry-C										
75'	26.3	23.9	42.9	38.9	62.9	57.2	84.5	76.6	176.1	161.2
150'	23.6	23.9	40.2·	36.9	57.5·	53.2	75.7·	70.2	155.9	146.3
N	26.9	24.4	43.7	39.5	63.0	57.3	83.3	75.8	165.9	153.6
W	28.7	25.7	47.5	42.3	70.5	62.8	89.3	80.2	168.3	155.4
BELT CONVEYOR										
Dry-UC										
75'	29.3	26.3	45.9	40.8	66.4	59.2	89.3	79.2	183.5	164.1
150'	28.3	25.6	41.6	37.7	58.6	53.4	76.9·	70.1	156.1	143.9
N	30.0	26.9	46.4	41.2	65.8	58.7	86.1	76.9	163.2	149.1
W	31.2	27.8	53.1	46.1	71.8	63.1	90.8	80.3	165.1	150.5
Dry-C										
75'	27.4	25.0	42.5	38.4	61.1	55.4	81.1	73.2	167.3	152.4
150'	27.4	25.0	39.8·	36.5	55.7·	51.4	72.3·	66.8	147.2·	137.6
N	28.0	25.5	43.3	39.1	61.2	55.5	79.9	72.4	157.1	144.9
W	29.8	26.8	47.1	41.8	68.6	61.0	85.9	76.8	159.5	146.7
PNEUMATIC CONVEYOR										
Dry-UC										
75'	27.4	24.4	44.4	39.3	65.2	58.0	88.6	78.6	183.8	164.4
150'	26.4	23.7	40.1·	36.2	57.5·	52.3	76.2·	69.4	156.4	144.2
N	28.1	25.0	44.9	39.7	64.6	57.6	85.4	76.2	163.5	149.4
W	29.3	25.9	51.5	44.6	70.6	62.0	90.1	79.6	165.4	150.8
Dry-C										
75'	25.5	23.1	40.9	36.9	59.9	54.2	80.4	72.6	167.6	152.7
150'	25.5	23.1	38.3·	35.0	54.5·	50.3	71.6·	66.1	147.5·	137.9
N	26.1	23.6	41.8	37.5	60.0	54.3	79.2	71.7	157.4	145.2
W	27.9	24.9	45.5	40.3	67.5	60.8	85.2	76.1	159.8	146.9

*Least cost option per column.
·Less than 15 percent greater than least cost option.

Key: 25', 50', 75', 150' = Depth of disposal area
N = Narrow valley
W = Wide valley

C = Compacted
UC = Uncompacted

Table 9-2

ASH DISPOSAL SYSTEM
TOTAL SYSTEM COST
(ALL COSTS IN MILLION $)

	300 MW		600 MW		900 MW		1300 MW		2600 MW	
Disposal Method	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner
PIPELINE										
Wet										
25'	286	201	482	317	677	432	921	570	1780	1083·
50'	339	294	494	413	648	530	838	671	1520	1195
N	186·	154·	310*	255·	430*	358	577*	485·	1087*	955*
W	192·	152*	315·	248*	435·	353*	578·	480*	1124·	961·
TRUCK TRANSPORT										
Dry-UC										
75'	256	233	413	373	601	545	827	749	1682	1531
150'	248·	227	380·	349	541	501	731	678	1470	1375
N	261·	237	417	377	596	542	802	731	1525	1417
W	271·	244	468	414	643	576	838	757	1539	1426
Dry-C										
75'	242*	224	387	356	581	537	764	703	1578	1463
150'	242*	223	367	341	539	506	696	653	1422	1348
N	247·	227	394	361	582	537	755	696	1499	1404
W	261·	237	423	382	640	580	801	731	1518	1417
BELT CONVEYOR										
Dry-UC										
75'	289	266	427	388	598	542	804	726	1606	1456
150'	281	261	394	363	537	497	708	655	1394	1300
N	294	270	431	391	593	538	779	708	1449	1340
W	304	278	482	428	639	572	816	734	1464	1351
Dry-C										
75'	275·	257	401	370	577	533	741	680	1503	1387
150'	275·	256	381	355	535	502	673	630	1346	1272
N	280	260	408	375	578	534	732	673	1424	1329
W	294	270	437	396	636	576	778	708	1442	1342
PNEUMATIC CONVEYOR										
Dry-UC										
75'	260·	237	404	365	581	525	796	717	1613	1463
150'	252·	232	371	341	521	481	700	647	1401	1307
N	265·	241	409	368	577	521	771	699	1456	1347
W	275·	249	460	406	623	556	807	726	1471	1358
Dry-C										
75'	246·	228	379	348	561	517	733	672	1510	1394
150'	246·	227	358	332	519	486	664·	622	1354	1279
N	251·	231	385	353	562	518	723	665·	1431	1336
W	265·	241	414	314	620	560	770	699	1449	1350

*Least cost option per column.

·Less than 15 percent greater than least cost option.

Key: 25', 50', 75', 150' = Depth of disposal area
N = Narrow valley
W = Wide valley
C = Compacted
UC = Uncompacted

	r	x	i
Present Worth	11%	2.3%	8.5%
Total System Cost	20.4%	11.0%	8.5%

ASH DISPOSAL COSTS

A summary of disposal system costs are included in Tables 9-1 and 9-2. As detailed in Appendix A, the cost estimates for ash handling, transport, and disposal include many assumptions. To obtain transportation and disposal area capital and O&M costs for the different alternatives, detailed calculations were performed. Budget estimates of capital costs for the in-plant handling systems based on 17 percent of the capital cost (11) plus 8.5 percent inflation. The cost of in-plant handling systems has been summarized in Table 9-3. These costs reflect only the average of suppliers whose equipment is commonly installed in power plants within the United States. These costs varied appreciably as shown on Table 5-2. Appendices B and C are line item cost estimates for the 2600 MW power plant with a lined disposal area in a narrow valley. Dry compacted ash disposal is detailed in Appendix B and wet disposal is detailed in Appendix C. Line item cost estimates were made for each of the disposal system alternatives for the five power plants. In addition to the total cost of disposal, the cost per ton of dry ash disposed was developed to provide a common basis for comparison of disposal costs. This analysis is included in Tables 9-4 and 9-5. To illustrate the effect of the in-plant handling system on overall system economics, Table 9-6 was developed to indicate the total system cost of the transportation and disposal area only.

COST ANALYSIS RESULTS

The results of the cost analysis indicated a range of disposal costs as follows:

RANGE OF ASH DISPOSAL COSTS ($/DRY TON DISPOSED)

	Present Worth	Total System Cost
Dry Disposal	$2.19 - $4.50	$20.65 - $40.00
Wet Disposal	$1.86 - $5.68	$15.93 - $42.30

The results of these analyses, as shown in Tables 9-1, 9-3, 9-4, and 9-5, indicate comparisons of both wet and dry options, transport options, disposal area topography, use of a liner and ash compaction.

Table 9-3

COST ANALYSIS*
IN-PLANT HANDLING SYSTEM
(ALL COSTS IN MILLION $)

Item	300 MW	600 MW	900MW	1300 MW	2600 MW
CAPITAL COST					
Wet	0.9	1.9	2.8	3.7	8.5
Dry	2.8	4.3	6.5	8.5	19.5
WEIGHTED CAPITAL COST					
Wet	7.0	14.7	21.7	28.7	65.9
Dry	21.7	33.4	50.4	65.9	151.2
35-YEAR O&M COST					
Wet	32	67	100	132	302
Dry	100	153	231	302	693
PRESENT WORTH OF 35-YEAR O&M COST					
Wet	.8	1.8	2.6	3.4	7.8
Dry	2.6	4.0	6.0	7.8	18.0
SYSTEM PRESENT WORTH					
Wet	1.7	3.7	5.4	7.1	16.3
Dry	5.4	8.3	12.5	16.3	37.5
SYSTEM TOTAL COST					
Wet	39.0	81.7	121.7	160.7	367.9
Dry	121.7	186.4	281.4	367.9	844.2

*All costs in million dollars.

Table 9-4

ASH DISPOSAL SYSTEM
COST PER DRY TON DISPOSED AT PRESENT WORTH COST
(ALL COST IN $)

Disposal Method	300 MW		600 MW		900 MW		1300 MW		2600 MW	
	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner
PIPELINE										
Wet										
25'	4.69	3.12	4.14	2.61	3.92	2.41	3.73	2.22	3.69	2.20
50'	5.68	4.85	4.25	3.50	3.74	3.01	3.37	2.66	3.14	2.44
N	2.83	2.24	2.53	2.04	2.40	1.95	2.26	1.86	2.21	1.93
W	2.95	2.20	2.59	1.97	2.42	1.91	2.26	1.84	2.29	1.99
TRUCK TRANSPORT										
Dry-UC										
75'	4.06	3.63	3.33	2.97	3.27	2.93	3.08	2.74	3.19	2.87
150'	3.92	3.53	3.03	2.74	2.90	2.65	2.67	2.44	2.74	2.53
N	4.16	3.71	3.37	3.00	3.24	2.90	2.97	2.66	2.85	2.62
W	4.34	3.85	3.85	3.35	3.53	3.11	3.13	2.78	2.89	2.64
Dry-C										
75'	3.79	3.45	3.09	2.80	3.02	2.74	2.80	2.54	2.92	2.67
150'	3.78	3.44	2.89	2.65	2.76	2.55	2.51	2.33	2.59	2.43
N	3.88	3.51	3.15	2.84	3.02	2.75	2.76	2.52	2.75	2.55
W	4.13	3.70	3.42	3.04	3.38	3.01	2.96	2.66	2.79	2.58
BELT CONVEYOR										
Dry-UC										
75'	4.21	3.79	3.30	2.94	3.18	2.84	2.97	2.63	3.05	2.72
150'	4.07	3.69	2.99	2.71	2.81	2.56	2.55	2.33	2.59	2.39
N	4.31	3.87	3.34	2.97	3.15	2.82	2.86	2.55	2.71	2.48
W	4.50	4.00	3.82	3.32	3.44	3.03	3.01	2.67	2.74	2.50
Dry-C										
75'	3.95	3.60	3.06	2.77	2.93	2.66	2.69	2.43	2.78	2.53
150'	3.94	3.59	2.86	2.62	2.67	2.47	2.40	2.22	2.44	2.28
N	4.03	3.67	3.12	2.81	2.93	2.66	2.65	2.40	2.61	2.40
W	4.29	3.86	3.38	3.01	3.29	2.92	2.85	2.55	2.65	2.43
PNEUMATIC CONVEYOR										
Dry-UC										
75'	3.94	3.52	3.19	2.83	3.13	2.78	2.94	2.61	3.05	2.73
150'	3.80	3.41	2.89	2.60	2.76	2.51	2.53	2.30	2.60	2.39
N	4.04	3.60	3.23	2.86	3.10	2.76	2.84	2.53	2.71	2.48
W	4.22	3.73	3.71	3.21	3.39	2.97	2.99	2.64	2.74	2.50
Dry-C										
75'	3.67	3.33	2.95	2.66	2.87	2.60	2.67	2.41	2.78	2.53
150'	3.66	3.32	2.75	2.51	2.62	2.41	2.38	2.19	2.45	2.29
N	3.76	3.39	3.01	2.70	2.88	2.61	2.63	2.38	2.61	2.41
W	4.01	3.58	3.28	2.90	3.24	2.92	2.83	2.53	2.65	2.44

Key: 25', 50', 75', 150' = Depth of disposal area
N = Narrow valley
W = Wide valley
C - Compacted
UC = Uncompacted

Table 9-5

ASH DISPOSAL SYSTEM
COST PER DRY TON AT TOTAL SYSTEM COST
(ALL COSTS IN $)

Disposal Method	300 MW		600 MW		900 MW		1300 MW		2600 MW	
	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner
PIPELINE										
Wet										
25'	41.15	28.92	34.68	22.81	32.47	20.72	30.57	18.92	29.55	17.98
50'	48.78	42.30	35.54	29.71	31.08	25.42	27.82	22.28	25.23	19.84
N	26.76	22.16	22.30	18.35	20.62	17.17	19.15	16.10	18.04	15.85
W	27.63	21.87	22.68	17.84	20.86	16.93	19.19	15.93	18.66	15.95
TRUCK TRANSPORT										
Dry-UC										
75'	36.84	33.53	29.71	26.84	28.83	26.14	27.45	24.86	27.92	25.41
150'	35.69	32.66	27.34	25.11	25.95	24.03	24.27	22.51	24.40	22.82
N	37.56	34.10	30.00	27.12	28.54	26.00	26.62	24.27	25.31	23.52
W	39.00	35.11	33.67	29.79	30.84	27.63	27.82	25.13	25.54	23.67
Dry-C										
75'	34.82	32.23	27.84	25.61	27.87	25.76	25.36	23.34	26.19	24.28
150'	34.82	32.09	26.40	24.53	25.85	24.27	23.10	21.68	23.60	22.37
N	35.54	32.66	28.35	25.97	27.92	25.76	25.06	23.10	24.88	23.30
W	36.56	34.10	30.43	27.48	30.70	27.82	26.59	24.27	25.20	23.52
BELT CONVEYOR										
Dry-UC										
75'	41.59	38.27	30.72	27.92	28.68	26.00	26.69	24.10	26.66	24.17
150'	40.43	37.56	28.35	26.12	25.76	23.84	23.50	21.74	23.14	21.58
N	42.30	38.85	31.01	28.13	28.44	25.80	25.86	23.50	24.05	22.24
W	43.74	40.00	34.89	30.79	30.65	27.44	27.09	24.37	24.30	22.42
Dry-C										
75'	39.57	36.98	28.85	26.62	27.68	25.57	24.60	22.57	24.95	23.02
150'	39.57	36.84	27.41	25.54	25.66	24.08	22.34	20.91	22.34	21.11
N	40.29	37.41	29.35	26.98	27.72	25.61	24.30	22.34	23.64	22.06
W	42.30	38.85	31.44	28.49	30.51	27.63	25.83	23.50	23.93	22.28
PNEUMATIC CONVEYOR										
Dry-UC										
75'	37.41	34.10	29.07	26.26	27.87	25.18	26.42	23.80	26.77	24.28
150'	36.26	33.38	26.69	24.53	24.99	23.07	23.24	21.48	23.25	21.69
N	38.13	34.68	29.43	26.48	27.68	24.99	25.59	23.20	24.17	22.36
W	39.57	35.83	33.10	29.21	29.88	26.67	26.79	24.10	24.42	22.54
Dry-C										
75'	35.40	32.81	27.27	25.04	26.91	24.80	24.33	22.31	25.06	23.14
150'	35.40	32.66	25.76	23.89	24.89	23.31	22.04	20.65	22.47	21.23
N	36.12	33.24	27.70	25.40	26.96	24.85	24.00	22.08	23.75	22.18
W	38.13	34.68	29.79	22.59	29.74	26.86	25.56	23.20	24.05	22.41

Key: 25', 50', 75', 150' = Depth of disposal area
N = Narrow valley
W = Wide valley
C = Compacted
UC = Uncompacted

Table 9-6

ASH DISPOSAL SYSTEM (TRANSPORTATION + DISPOSAL AREA)
TOTAL SYSTEM COST
(ALL COSTS IN MILLION $)

	300 MW		600 MW		900 MW		1300 MW		2600 MW	
Disposal Method	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner
PIPELINE										
Wet										
25'	253	168	413	248	574	329	785	434	1469	772
50'	306	261	425	344	545	427	702	535	1209	884
N	153·	121	241	186	327	255	441	349	776	644
W	159·	119	246	179	332	250	442	344	813	650
TRUCK TRANSPORT										
Dry-UC										
75'	135·	112·	227	187	320	264	459	381	838	687
150'	127·	106·	194·	163·	260	220·	363	310	626	531
N	140	116·	231	191	315	261	434	363	681	573
W	150	123	282	228	362	295	470	389	695	582
Dry-C										
75'	121*	103·	201	170	300	256	396	335	734	619
150'	121*	102*	181·	155·	258·	225·	328·	285·	578	504
N	126·	106·	208	175	301	256	387	328	655	560
W	140	116·	237	196	359	299	433	363	674	573
CONVEYOR TRANSPORT										
Dry-UC										
75'	168	145	241	202	317	261	436	358	762	612
150'	160	140	208	177	256·	216·	340·	287·	550·	456·
N	173	149	245	205	312	257	411	340	605	496
W	183	157	296	242	358	291	448	366	620	507
Dry-C										
75'	154	136	215	184	296	252	373	312	659	543
150'	154	135	195·	169	254·	221·	305·	262·	502*	428*
N	159	139	222	189	297	253	364	305	580	485·
W	173	149	251	210	355	295	410	340	598	498
PNEUMATIC TRANSPORT										
Dry-C										
75'	139·	116·	218	179	300	244	428	349	769	619
150'	131·	111·	185·	155·	240·	200*	332·	279·	557·	463·
N	144	120	233	182	296	240	403	331	612	503
W	154	128	274	220	342	275	439	358	627	514
Dry-C										
75'	125·	107·	193	162·	280	236	365	304	666	550
150'	125·	106·	172*	146*	238*	205·	296*	254*	510·	435·
N	130·	110·	199	167·	281	237	355	297	587	492·
W	144	120	228	188	339	279	402	331	605	506

*Least cost option per column.

·Less than 15 percent greater than least cost option.

Key:
25', 50', 75', 150' = Depth of disposal area
N = Narrow valley
W = Wide valley
C = Compacted
UC = Uncompacted

A comparison between Tables 9-1 and 9-2 does not indicate a significant difference in ash system economics based on the method of analysis. Present worth analysis, as shown in Table 9-1, indicates that wet disposal is typically the least cost alternative. However, various dry disposal options are within a 15 percent range of those costs. The costs are, in fact, sensitive to spreading the dry disposal area capital costs over the life of the power station and the in-plant handling system cost. Use of either the lower dilute phase transport system cost or the dense phase collection system cost results in the dry disposal system alternative becoming the least cost alternative. Review of Table 9-1 with respect to disposal area topographic condition indicates that although wet disposal may be the least cost option for valley areas, it is not economical for flat disposal areas. Total system analysis, as shown in Table 9-2, also indicates that although wet disposal is the typical least cost alternative, dry disposal is often a reasonable alternative. Again, as in Table 9-1, dry disposal is the least cost alternative for flat areas.

To provide a cost comparison between this analysis and other ash disposal cost studies, Table 9-6 has been included. Table 9-6 provides a total system cost analysis for only the transportation and disposal area. This analysis indicates that dry disposal is the typical least cost alternative.

In reviewing both the method and results of the economic analysis, it becomes apparent that the cost differential of the in-plant handling systems is sufficient to drastically alter the selection of the least cost option. This is readily apparent in a comparison of Tables 9-2 and 9-6. In reviewing Table 9-6, which includes the total system cost of the transportation and disposal portions of the disposal system, one can conclude that dry disposal is typically less expensive than wet disposal. In addition, it can be seen that flat dry sites are always the least cost alternative. However, when Table 9-2 is reviewed, which includes the total system cost of the in-plant handling system with the transportation and disposal area cost, one can conclude that wet disposal provides a significant number of the least cost alternatives although the majority of least cost options are dry alternatives. Also, the wet valley sites are typically the lesser cost of the wet options.

As the above comparison between cost estimates with and without in-plant handling systems indicates, the in-plant system cost alters the selection of the least cost system. Due to the magnitude of this change, a review of in-plant handling economics is in order.

The capital costs of the in-plant ash handling systems were obtained by the equipment suppliers based on the assumptions provided in Appendix A. Due to the similarities of their estimates and the plant generalities involved, these estimates were averaged and rounded off. To provide for an annual O&M cost of the in-plant system, an annual charge of 17 percent of the system capital cost was assessed to cover operation, maintenance, replacement, etc.

This annual cost was then inflated at the 8.5 percent inflation rate and a total system O&M cost determined. Table 9-3 indicates the capital and O&M costs involved with the in-plant system. Since these costs are sufficient to alter the final system selection, and due to the lack of specificity in the 17 percent O&M cost, a review of the effects of O&M is in order. Table 9-7 includes a re-analysis of the in-plant system O&M based on a 5 percent and 10 percent factor. These O&M costs have been used to revise the total system cost estimates for the 1300 and 2600 MW power plants. This comparison is shown in Table 9-8 and indicates that as the O&M cost of the in-plant handling system decreases, the use of dry disposal becomes more desirable. As previously mentioned, the variations in budget estimates from the manufacturers is significant. Using either an average of the most experienced U. S. suppliers or the higher costs of those suppliers leads to the results reported herein. However, if the lower estimates are utilized in the cost estimates, then it can be concluded that the dry systems do provide the least cost system.

The above analyses were performed on data that would generally be considered preliminary estimates and as such be accurate within 25 percent. Due to the variance of these estimates, site specific conditions could alter the ranking of the disposal systems alternatives. Thus, these analyses should only be used for generally comparative purposes. In addition, site specific conditions could substantially alter the analyses and, ultimately, the ranking. A specific example would be a site where a dam or levee would produce a disproportionate storage volume. Other situations could preclude the use of a specific system. An example would be a site which was not amenable to or was unsuitable for other reasons such as excessive leakage, unstable dam abutments, etc.

In addition, the above analyses assumed construction of all the required facilities upon start-up. In the case of dry disposal, this is a reasonable assumption although site preparation costs would proceed during the development of the site. In the case of wet disposal, it may be economically sound to construct the embankment in stages, even if the amount of material to be placed or the engineering estimate is higher for staged construction. This is due to the high cost of the dam or levee and the cost of money over the life of the project. As an example, the 2600 MW flat, wet disposal area was analyzed by all construction occurring in 1980 and by a staged construction sequence (3 stages). In this case, staged construction provided a 30 percent savings in the total cost of the system.

Table 9-7

COST REVIEW
IN-PLANT HANDLING SYSTEM
(ALL COSTS IN MILLION $)

Item	300 MW	600 MW	900 MW	1300 MW	2600 MW
CAPITAL COST					
Wet	0.9	1.9	2.8	3.7	8.5
Dry	2.8	4.3	6.5	8.5	19.5
WEIGHTED CAPITAL COST					
Wet	7.0	14.7	21.7	28.7	65.9
Dry	21.7	33.4	50.4	65.9	151.2
1ST YEAR O&M COST					
@ 10 PERCENT					
Wet	.09	.19	.28	.37	.85
Dry	.28	.43	.65	.85	1.95
@ 5 PERCENT					
Wet	.045	.095	.14	.185	.425
Dry	.14	.215	.325	.425	.975
35-YEAR O&M COST					
@ 10 PERCENT					
Wet	18.8	39.7	58.5	77.4	177.7
Dry	58.5	89.9	135.9	177.7	407.7
@ 5 PERCENT					
Wet	9.4	19.9	29.3	38.7	88.9
Dry	29.3	45.0	68.0	88.9	203.9
PRESENT WORTH OF 35-YEAR O&M COST					
@ 10 PERCENT					
Wet	0.5	1.0	1.5	2.0	4.6
Dry	1.5	2.3	3.5	4.6	10.6
@ 5 PERCENT					
Wet	0.2	0.5	0.8	1.0	2.3
Dry	0.8	1.2	1.8	2.3	5.3

Table 9-7

COST REVIEW
IN-PLANT HANDLING SYSTEM
(Continued)

Item	300 MW	600 MW	900 MW	1300 MW	2600 MW
PRESENT SYSTEM WORTH					
@ 10 PERCENT					
Wet	1.4	2.9	4.3	5.7	13.1
Dry	4.3	6.6	10.0	13.1	30.1
@ 5 PERCENT					
Wet	1.1	2.4	3.6	4.7	10.8
Dry	3.6	5.5	8.3	10.8	24.8
TOTAL SYSTEM COST					
@ 10 PERCENT					
Wet	25.8	54.4	80.2	106.1	243.6
Dry	80.2	123.3	186.3	243.6	558.9
@ 5 PERCENT					
Wet	16.4	34.6	51.0	67.4	154.8
Dry	51.0	78.4	118.4	154.8	355.1

Table 9-8

TOTAL SYSTEM COST COMPARISON FOR
ALTERNATE IN-PLANT HANDLING SYSTEM O&M COSTS
(ALL COSTS IN MILLION $)

	5 Percent O&M				10 Percent O&M				17 Percent O&M			
	1300 MW		2600 MW		1300 MW		2600 MW		1300 MW		2600 MW	
Disposal Method	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner	With Liner	Without Liner
PIPELINE												
Wet												
25'	852	501	1623	926	891	540	1713	1016·	921	570	1780	1083·
50'	794	602	1363	1038	808	641	1453	1128	838	671	1520	1195
N	534	416·	848*	798·	547·	455·	1020*	888*	577*	485·	1087*	955*
W	535	411·	886·	804·	548·	450*	1057·	894·	578·	480*	1124·	961·
TRUCK TRANSPORT												
Dry-UC												
75'	614	536	1193	1042	703	625	1397	1246	827	749	1682	1531
150'	518·	465·	981·	886·	607·	554	1185	1090	731	678	1470	1375
N	589	518	1036	928	678	607	1240	1132	802	731	1525	1417
W	625	544	1050	937	714	633	1254	1141	838	757	1539	1426
Dry-C												
75'	551	490	1089	974	640	579	1852	1178	764	703	1578	1463
150'	483	440·	933·	859·	572·	529	1137·	1063	696	653	1422	1348
N	542	483	1010	915	631	572	1214	1119·	755	696	1499	1404
W	588	517	1029	929	677	591	1233	1133	801	731	1518	1417
CONVEYOR TRANSPORT												
Dry-UC												
75'	591	513	1117	967	680	602	1321	1171	804	726	1606	1456
150'	495·	442·	905·	811	584·	531	1109·	1015·	708	655	1394	1300
N	566	495	960·	851·	655	584	1164·	1055	779	708	1449	1340
W	603	521	975·	862·	692	610	1179	1066	816	734	1464	1351
Dry-C												
75'	528	467·	1014	898·	617·	556	1218	1102	741	680	1503	1387
150'	460·	417·	857*	783*	549·	506·	1061	987·	673	630	1346·	1272
N	519	460·	935·	840·	608·	549	1139·	1044	732	673	1424	1329
W	565	495	953·	853·	654	584	1157·	1057	778	708	1442	1342
PNEUMATIC TRANSPORT												
Dry-UC												
75'	583	504	1124	974	672	593	1328	1178	796	717	1613	1463
150'	487·	434·	912·	818·	576·	523	1116·	1022	700	647	1401	1307
N	558	486	967	858·	647	575	1171·	1062	771	699	1456	1347
W	594	513	982	869·	683	602	1186	1073	807	726	1471	1358
Dry-C												
75'	520	459·	1021	905	609·	548	1225	1109	733	672	1510	1394
150'	451*	409*	865·	790·	540*	498·	1069·	994·	664·	622	1354	1279
N	510·	452·	942·	847·	599·	541	1146·	1051	723	665	1431	1336
W	557	486	960·	861·	646	575	1164·	1065	770	699	1449	1350

*Least cost option for station size.
·Less than 15 percent greater than least cost option.

Key: 25', 50', 75', 150' = Depth of disposal area
N = Narrow valley
W = Wide valley
C = Compacted
UC = Uncompacted

SECTION 10

CONCLUSIONS

Upon review of the economic comparisons described in Section 9, it becomes apparent that the method of economic analysis is not a primary factor in the selection of an ash disposal system. The system selection is dependent more on site topography and in-plant handling system costs. In general, dry ash disposal is the least cost alternative for flat areas whereas wet ash disposal is the least cost option for valley disposal. However, this assumes that the valley is amenable to wet disposal. Although no overall system selection generalities can be made, certain trends have been identified for the specific conditions studied. These include:

- Dry compacted ash disposal costs less than uncompacted ash disposal;
- The use of a liner significantly increases the cost of the ash disposal system and could alter the system selection from dry to wet or vice-versa;
- As the cost of in-plant handling system O&M is decreased, the use of dry disposal becomes more advantageous;
- As the volume of ash disposed is increased, the cost per dry ton disposed, typically decreases;
- Comparison of valley disposal sites is sensitive to in-plant ash handling costs. A higher level of estimate for the in-plant handling system cost would be required to make an economic decision for the type of valley sites considered in this report. However, a higher level estimate would require plant layout details which were not a part of this present study;
- Economic comparisons of valley disposal sites can be sensitive to the method in which site preparation and embankment construction is phased. Although the analysis in this report considered all site preparation and construction to occur in the initial year, spreading site construction costs over the life of the power plant may alter the economic decision;
- In-plant handling system costs need further documentation and refinement. This is apparent since the use of the lower dilute phase system estimate, the dense phase system estimate, or an average cost utilizing the dense phase system results in the conclusion that dry disposal is cheaper in the valley disposal case.

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APPENDIX A

DESIGN CONDITIONS

Table A-1

POWER PLANT CHARACTERISTICS

Boiler Type	Pulverized Coal Dry Bottom
Coal Heat Content	10,500 btu/lb
Coal Type	Subbituminous
Plant Heat Rate	10,000 btu/kw hr
Plant Life	35 Years
Plant Capacity Factor	80 Percent
Plant Generating Capacity	300 MW, 600 MW, 900 MW, 1300 MW, 2600 MW
Plant Location	Southeastern U. S.
Plant Altitude	Less than 2,000 feet (msl)
In-Plant Ash Transport Distance	400 Feet
Fly Ash to Bottom Ash Ratio	80:20
Coal Ash Content	20 Percent
Particulate Removal Devices	Cold-Side Electrostatic Precipitators
Fly Ash Collection Efficiency	99 Percent
Distance to Ash Disposal Site	1 Mile

Table A-2

ASH QUANTITIES

Plant Size (MW)	Bottom Ash (tons/day)*	Fly Ash (tons/day)*
300	110	434
600	219	869
900	329	1303
1300	475	1883
2600	951	3765

*Daily average based on 80 percent load factor.

Table A-3

ASH DENSITIES*

Method of Ash Placement	Bottom Ash (lb/ft^3)	Fly Ash (lb/ft^3)
Wet (Slurry)	60	40
Dry Uncompacted	80	60
Dry Compacted	100	80

*All densities are expressed as dry bulk densities.

Table A-4

SITE PREPARATION COSTS

Land	$1,500/acre
Drainage Ditch (dry site)	$30/linear foot
Clearing and Grubbing	$1,500/acre
Stripping and Stockpiling Soil	$3/cubic yard
Seeding	$1,000/acre
Haul Road	$20/linear foot
Site Liner	$5.50/square yard
Drainage Blanket (dry site)	$1.50/square foot
8-Inch Diameter Drainage Pipe (dry site)	$10/linear foot
Embankment Construction (wet site)	$5/cubic yard
Sedimentation Pond (dry site)	$15,000 each
Appurtenances (wet site)	
High embankment (>50')	$100,000
Low embankment (≤50')	$25,000

Table A-5

MACHINE OPERATING COSTS

Operator	$20.16/hr*
Oiler	$12.75/hr*
Fuel	$ 1.00/gallon
Maintenance	
Front-end loader - Cat 9666	$ 0.50/hr
Dredge - Mud Cat MC-915	$ 0.66/hr
25-ton triaxle truck	$ 0.60/hr

*Man-hour costs are twice the hourly pay rate to include benefits and supervision.

Note: Payrates were estimated from the Tennessee Valley Authority Schedule of Trades and Labor Classifications, Minimum hourly rates of pay and minimum fringe benefits on work performed under TVA Contract.

Table A-6

DRY DISPOSAL SITE CHARACTERISTICS

Fill Height	
Flat Site	75 and 150 feet*
Valley Site	As Required
Fill Width	
Flat Site	2,500 feet
Valley Site	As Required
Fill Side Slopes	
Maximum	3 horizontal to 1 vertical
Overall	4 horizontal to 1 vertical
Terrace Height	25 feet
Terrace Width	25 feet
Drainage Blanket Thickness	1 foot
Drainage Ditch Length	1.5 x site perimeter**
Drainage Pipe Length	2 x site length**
Haul Road (on-site)	.5 x site length**

NUMBER OF SEDIMENTATION PONDS (DRY SITE)

300 MW, 600, MW, 900 MW	1
1300 MW	2
2600 MW	4

*Both cases considered to allow for specific site variations in soils, geology and topography.

**General design conditions based on disposal areas located in similar topographic areas.

Table A-7

ASH HAULING AND PLACEMENT EQUIPMENT

Equipment	Initial Cost	Estimated Life	Fuel Consumption	Cycle Time*
Front-end loader (Cat 966C)	$119,000	7 yrs	8.4 gal/hr	
Roller (Essex 42 RTE)	24,000	15 yrs		
25-ton triaxle (International Harvestor 5,070)	65,000	10 yrs	8.0 gal/hr***	13.5 min
Dredge (Mud Cat MC-915)	103,266**		6.5 gal/hr	

*Time required to load, haul one mile, dump, and return to reload.

**Rental cost for one year. Actual site costs were based on utilizing a dredge for redistributing the ash on an occasional basis based on pond size.

***Although 5.0 gallons per hour was used in the truck transport comparison (Table 7-2), 8.0 gallons per hour were utilized in the final estimates to compensate for the effects of haul road grades, idling, inefficient operation, and other variable factors.

Table A-8

DRY DISPOSAL YEARLY OPERATIONAL HOURS

	Plant Size				
	300	600	900	1300	2600
COMPACTED SITE					
Front-end loader	600	1600	2400	3400	5000
Roller	100	400	400	600	1000
Oiler	300	800	1200	1600	2000
Operator	800	2000	3000	4000	6000
UNCOMPACTED SITE					
Front-end loader	500	1200	2000	2800	4000
Oiler	300	600	1000	1400	2000
Operator	600	1400	2400	4000	5000

Table A-9

WET DISPOSAL SITE CHARACTERISTICS

Embankment Heights	25 and 50 feet*
Width of Embankment (Flat Site Only)	5000 feet
Freeboard	5 feet
Embankment Crest Width	25 feet
Embankment Side Slopes	3 horizontal to 1 vertical

*Both cases considered to allow for specific variations in soils, geology and topography.

Table A-10

ASH SLURRY PUMPS

Plant Size (MW)	Pump Size (HP)	Pump Cost ($)*
300	50	$3,500
600	60	3,500
900	75	5,200
1,300	100	5,200
2,600	125	5,200

*Purchase price based on manufacturers data.

Table A-11

ASH SLUICE LINES*

Plant Size (MW)	Slurry Pipe Diameter (in.)	Pipe Cost** ($/ft)	Number of Pipelines***	Total Pipeline Cost ($/ft)
300	8	$10.46	3	$ 31.38
600	8	10.46	4	41.84
900	10	13.27	4	53.08
1300	10	13.27	5	66.35
2600	12	15.64	7	109.48

*Sluice lines were assumed to have a four-year life.

**Installed cost per linear foot of a single cast iron pipe.

***Number of pipelines includes one additional line to allow for maintenance and/or breakdowns.

Table A-12

SLURRY PIPELINE CHARACTERISTICS

Slurry	10 Percent Solids
Slope to Disposal Site	10 Percent
Distance to Disposal Site	1 Mile
Maximum Flow	2 x Average
Pumping TDH	100 Feet
System Operation	7 days/week; 24 hours/day

Table A-13

RETURN WATER LINES*

Plant Size (MW)	Design Flow (cfs)	Pipe Diameter (in.)	Pipe Cost** ($/ft)	Number of Pipelines***	Total Pipeline Cost ($/ft)
300	5.3	10	$13.27	2	$26.54
600	10.6	14	18.64	2	37.28
900	15.9	12	15.64	3	46.92
1300	22.9	14	18.64	3	55.92
2600	45.8	16	24.80	4	99.20

*Water return lines were assumed to have a 20-year life.

**Installed cost per linear foot of a single cast iron pipe.

***Number of pipelines includes one additional line to allow for maintenance and/or breakdowns.

Table A-14

WET DISPOSAL YEARLY MAINTENANCE HOURS

	Plant Size (MW)				
	300	600	900	1300	2600
Front-end loader	200	400	600	800	1000
Dredge	200	400	600	800	1000
Oiler	200	400	600	800	1000
Operator	500	1000	1500	2000	3000

Note: Maintenance hours were based on typical pond embankment maintenance/repair conditions.

Table A-15

BELT CONVEYOR**

Plant Size (MW)	Belt Width (in.)	Cost* (Million Dollars)
300	18	2.38
600	18	2.38
900	18	2.38
1,300	18	2.38
2,600	36	2.97

*Cost for installed enclosed belt conveyor as supplied by Can-Belt International.

Table A-16

FLY ASH STORAGE SILO

Plant Size (MW)	Silo Capacity (tons)	Installed Cost* (million dollars)
300	2,310	.35
600	4,620	.70
900	6,930	1.10
1,300	10,011	1.55
2,600	20,022	2.95

*Cost for installed silo as supplied by First Colony Corporation.

B-0

APPENDIX B

APPENDIX B
LINE ITEM COST ESTIMATE
2600 MW POWER PLANT WITH DRY ASH DISPOSAL
NARROW VALLEY WITH LINER

Design Conditions:

Plant:

Size (units)	2600 MW (3 at 867 MW)
Disposal Method	Dry Disposal (compacted)
Disposal Area	Narrow Valley with Liner
Plant Load Factor	80 Percent
Fly Ash Collection Efficiency	99 Percent
Ash Content	20 Percent
Fly Ash/Bottom Ash Ratio	80/20

CALCULATION OF WASTE QUANTITIES

1. Coal Consumption

a. @ 100 Percent Load Factor

$$2600\ \left(\frac{\text{MW}}{\text{hr}}\right)\text{x}10^3\left(\frac{\text{kw}}{\text{MW}}\right)\text{x}10{,}000\left(\frac{\text{Btu}}{\text{kw}}\right)\text{x}\frac{1}{10{,}500}\left(\frac{\text{lb}}{\text{Btu}}\right)\text{x}\frac{1}{2000}\left(\frac{\text{ton}}{\text{lb}}\right) = 1238\left(\frac{\text{t-coal}}{\text{hour}}\right)$$

$$1238\left(\frac{\text{t-coal}}{\text{hour}}\right)\text{x}24\left(\frac{\text{hours}}{\text{day}}\right)\text{x}365\left(\frac{\text{days}}{\text{year}}\right) = 10{,}845{,}714\left(\frac{\text{t-coal}}{\text{year}}\right)$$

b. @ 80 Percent Load Factor

$$1238\ \left(\frac{\text{t-coal}}{\text{hour}}\right)\text{x}0.80 = 990\left(\frac{\text{t-coal}}{\text{hour}}\right)$$

$$10{,}845{,}714\left(\frac{\text{t-coal}}{\text{hour}}\right)\text{x}0.80 = 8{,}676{,}571\left(\frac{\text{t-coal}}{\text{year}}\right)$$

2. Ash Produced

a. Total Ash @ 100 Percent Load Factor

$$1238\left(\frac{\text{t-coal}}{\text{hour}}\right)\text{x}0.20 = 248\left(\frac{\text{t-ash}}{\text{hour}}\right)$$

$$10{,}845{,}714\left(\frac{\text{t-coal}}{\text{year}}\right)\text{x}0.20 = 2{,}169{,}143\left(\frac{\text{t-ash}}{\text{year}}\right)$$

@ 80 Percent Load Factor

$$990\left(\frac{\text{t-coal}}{\text{hour}}\right)\text{x}0.20 = 198\left(\frac{\text{t-ash}}{\text{hour}}\right)$$

$$8,676,571\left(\frac{\text{t-coal}}{\text{year}}\right)\text{x}0.20 = 1,735,314\left(\frac{\text{t-ash}}{\text{year}}\right)$$

b. Fly Ash - @ 100 Percent Load Factor

$$248\left(\frac{\text{t-ash}}{\text{hour}}\right)\text{x}0.80 = 198\left(\frac{\text{t-FA}}{\text{hour}}\right)$$

$$2,169,143\left(\frac{\text{t-ash}}{\text{year}}\right)\text{x}0.80 = 1,735,314\left(\frac{\text{t-FA}}{\text{year}}\right)$$

@ 80 Percent Load Factor

$$198\left(\frac{\text{t-FA}}{\text{year}}\right)\text{x}0.80 = 158\left(\frac{\text{t-FA}}{\text{year}}\right)$$

$$1,735,314\left(\frac{\text{t-FA}}{\text{year}}\right)\text{x}0.80 = 1,388,251\left(\frac{\text{t-FA}}{\text{year}}\right)$$

c. Bottom Ash - @ 100 Percent Load Factor

$$248\left(\frac{\text{t-ash}}{\text{hour}}\right)\text{x}0.20 = 50\left(\frac{\text{t-BA}}{\text{hour}}\right)$$

$$2,169,143\ \left(\frac{\text{t-ash}}{\text{year}}\right)\text{x}0.20 = 433,829\left(\frac{\text{t-BA}}{\text{year}}\right)$$

@ 80 Percent Load Factor

$$50\left(\frac{\text{t-BA}}{\text{hour}}\right)\text{x}0.80 = 40\left(\frac{\text{t-BA}}{\text{hour}}\right)$$

$$433,829\left(\frac{\text{t-BA}}{\text{year}}\right)\text{x}0.80 = 347,063\left(\frac{\text{t-BA}}{\text{year}}\right)$$

ESTIMATED COST OF A NARROW VALLEY DRY ASH DISPOSAL AREA

1. Assumptions:

Useful Life	35 yrs
Power Station Load Factor	80 Percent
Depth of Fill	200 ft
Compacted Density	80 lb/ft^3
Dry Density of Fly Ash	60 lb/ft^3
Side Slopes	3 horizontal to 1 vertical
Benches	25 ft high

2. Design Parameters:

Site Perimeter = 14,520 ft[a]

Site Length = 6,400 ft[a]

On-Site Haul Road Length = 1/2 x Site Length = 3,200 ft

Drainage Ditch = 1.5 x Perimeter = 21,780 ft

Drainage Pipe = 2 x Site Length = 12,800 ft

Area = Top Surface Area + Bench and Embankment Area*

= 436 + 23.5

= 459.5 acres

Stripping and Stockpiling 6" Topsoil

$$459.5(\text{acres}) \times 43{,}560\left(\frac{ft^2}{acre}\right) \times \frac{1}{12}\left(\frac{ft}{in}\right) \times 6(\text{in}) \times \frac{1}{27}\left(\frac{yd}{ft^3}\right) = 370{,}663\ yd^3$$

Underdrainage Blanket

$$459.5(\text{acres}) \times 43{,}560\left(\frac{ft^2}{acre}\right) = 20{,}015{,}820\ ft^2$$

Liner

$$459.5(\text{acres}) \times 43{,}560\left(\frac{ft^2}{acre}\right) \times \frac{1}{9}\left(\frac{yd^2}{ft^2}\right) = 2{,}223{,}980\ yd^2$$

[a] Areas planimetered from preliminary design drawings.

3. Site Preparation Costs:

Land
459.5 acres x $1,500/acre = 689,250

Sedimentation Pond
4 x $15,000 each = 60,000

Drainage Pipe, 8" ϕ
12,800 LF x $10/LF = 128,000

Drainage Ditches
21,780 LF x $30/LF = 653,400

Underdrainage Blanket
20,015,820 SF x $1.50/SF = 30,023,730

Clearing and Grubbing
459.5 acres x $1,500/acre = 689,250

Stripping and Stockpiling 6" Topsoil
370,663 CY x $3/CY = 1,111,989

Seeding
459.5 acres x $1,000/acre = 459,500

On-Site Haul Road
3200 LF x $20/LF = 64,000

Liner
2,223,980 SY x $5.50/SY = 12,231,890

Site Preparation Capital Costs[b] = $46,111,009

---

[b] For present worth analysis, the initial equipment purchase is included with the capital cost.
[$46,111,000 + $286,000 = $46,397,000] (see Section 4g and 4h).

---

4. Site Operation Costs:

a. Front End Loader (Caterpillar 966C)

No. Required On-Site	2
Estimated Life	7 years
Present Cost	$119,000/unit
Total Capital Cost of Units	

Year	Capital Cost @ 2 Units Every 7 Years
1	$ 238,000
7	421,294
14	745,750
21	1,320,084
28	2,336,730
Total	$5,061,800

b. Towed Roller (Essex 42RTE, 3-5 ton)

No. Required On-Site	2
Estimated Life	15 years
Present Cost	$24,000/unit
Total Capital Cost of Units	

Year	Capital Cost
1	$ 48,000
15	200,106
Total	$248,106

c. Oiler

Hourly Wages	$6.375/hr
Overhead Rate	2.0
Total Wage Cost/Hour	$12.75
On-Site Hours/Year	2,000
Yearly Cost	$25,500

d. Operator

Hourly Wages	$10.08/hr
Overhead Rate	2.0
Total Wage Cost/Hour	$20.16/hr
On-Site Hours/Year	6,000
Yearly Cost	$120,960

e. Fuel

Fuel Consumption Rate	8.4 gal/hr
Fuel Cost	$1.00/gal
Yearly Operating Hours	5,000
Yearly Fuel Cost	$42,000

f. Maintenance and Lubrication

Average Cost	$0.50/operating hour
Yearly Operating Hours	5,000
Yearly Cost	$2,500

g. Site Operation Capital Cost[c]

Front End Loader	$5,061,800
Towed Roller	248,000
Total	$5,309,800

h. Site Operation Annual Costs[c]

Oiler	$ 25,500
Operator	120,960
Fuel	42,000
Lube & Misc.	2,500
Total	$190,960

i. Site Operation 35-Year Total Cost @ 8.5 Percent Inflation

$$\$190{,}960\left[\frac{(1 + 0.085)^{35+1} - 1}{0.085} - 1\right] = \$39{,}926{,}165^{*}$$

---

[c] For present worth analysis, only the initial equipment purchase is considered a capital expense. Therefore:

O&M Capital = $238,000 + $48,000 = $286,000

35-Year O&M = $39,926,000 + [5,309,800 - 286,000] = $44,950,000

---

5. Transportation Cost:

a. Capital Cost

Assumes truck transport via 25-ton triaxle diesel trucks (see Tables 7-1 and 7-2).

No. of Trucks Required	8
Estimated Life	10 years
Present Cost	$65,000/unit
Total Capital Cost of Units	

Year	Capital Cost[d]
1	$ 520,000
10	1,175,712
20	2,658,264
30	6,010,288
Total	$10,364,264

---

[d] However, only the initial purchase of 8 trucks is considered to be a capital cost under present worth analysis. Therefore, only $520,000 is considered a capital cost for the present worth analysis.

---

b. Operation and Maintenance Cost (O&M)

Oiler

Hourly Wages	$6.375/hr
Overhead Rate	2.0
Total Wage Cost/Hour	$12.75
Hours/Year	8,000
Yearly Cost	$102,000

Operator

Hourly Wages	$10.08/hr
Overhead Rate	2.0
Total Wage Cost/Hr	$20.16/hr
Hours/Year	$16,000
Yearly Cost	$322,560

Fuel

Fuel Consumption Rate	8 gal/hr
Fuel Cost	$1.00/gal
Yearly Operating Hours	15,700
Yearly Fuel Costs	$125,600

Maintenance and Lubrication

Average Cost	$0.60/operating hour
Yearly Operating Hours	15,700
Yearly Cost	$9,420

c. Annual Operation and Maintenance Cost

Oiler	$102,000
Operator	322,560
Fuel	125,600
Lube & Misc.	9,420
Total	$559,580

d. Transportation Operation and Maintenance 35-Year Cost @ 8.5 Percent Inflation

$\$559,580\left[\frac{(1 + 0.085)^{35+1} - 1}{0.085} - 1\right] = 116,996,000$[e]

---

[e] For present worth analysis, the future capital cost of the vehicles may be discounted. Therefore, \$10,364,264 - \$520,000 or \$9,844,264 is added to the O&M Cost for present worth analysis.

[\$116,996,000 + \$9,844,264 = \$126,840,000]

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6. In-Plant Handling System:

Capital Cost**	\$19,500,000
(**Manufacturers' data)	
Annual Operation and Maintenance Cost Percent of Capital Cost	\$3,315,000

35-Year O&M Cost @ 8.5 Percent Inflation

$$3,315,000\left[\frac{(1 + 0.085)^{35+1} - 1}{0.085} - 1\right] = \$693,100,000$$

7. Total System Cost:

Capital Cost		
In-Plant	\$ 19,500,000	
Transportation	10,364,000	
Disposal Area	46,111,000	+ 7,841,000
Total	\$ 83,816,000	
Weighted Cost of Capital	\$649,000,000	
Operation and Maintenance		
In-Plant	\$693,100,000	
Transportation	116,996,000	
Disposal Area	39,926,000	
Total	\$850,022,000	
Total System Cost	\$1,499,000,000	

PRESENT WORTH ANALYSIS

Inflation Rate: 8.5%
Cost of Capital: 2.3%
Discount Rate: 11%

Capital Cost

Disposal area (see pp. B-4)	$46,111,009
Front end loader (see pp. B-4,5) 2x119,000x[1+.84+.71+.60+.50]	868,700
Towed roller (see pp. B-5) 2x24,000x[1+.69]	81,120
Trucks (see pp. B-6) 8x65,000x[1+.78+.61+.48]	1,492,400
In-plant handling system	19,500,000
Total Capital Cost	$68,053,229

Note: Numbers in brackets [] are present worth factors based on the number of years to the expenditure and a 2.3% cost of capital.

Operation and Maintenance (O&M) Cost

Disposal area (see pp. B-5)

Oiler	$ 25,500/year
Operator	120,960/year
Fuel	42,000/year
Maint. and lubrication	2,500/year
Total	$190,960/year (see pp. B-6)

190,960x24.5[f] $ 4,678,520

Transportation (see pp. B-7)

Oiler	$102,000/year
Operator	322,560/year
Fuel	125,600/year
Maint. and lubrication	9,420/year
	$559,580/year (see pp. B-7)

559,580x24.5 $ 81,217,500

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[f] Present worth factor for an annual expenditure over 35 years at a 2.3% cost of capital.

In-plant handling system (see pp. B-8)

3,315,000x24.5		$ 81,217,500
	Total O&M Cost	$ 99,605,730
	Present Worth	$167,658,900

APPENDIX C

APPENDIX C
LINE ITEM COST ESTIMATE
2600 MW POWER PLANT WITH WET ASH DISPOSAL
NARROW VALLEY WITH LINER

Design Conditions

Plant:

Size (units)	2600 MW (3 at 867 MW)
Disposal Method	Wet Disposal
Disposal Area	Narrow Valley
Plant Load Factor	80 Percent
Fly Ash Collection Efficiency	99 Percent
Ash Content	20 Percent
Fly Ash/Bottom Ash	80/20

CALCULATION OF WASTE QUANTITIES

See Appendix B

ESTIMATED COST OF A NARROW VALLEY WET DISPOSAL SITE

1. Assumptions:

Useful Life	35 yrs
Power Station Load Factor	80 Percent
Embankment Height	255 ft
Freeboard	5 ft
Side Slopes	3 horizontal/1 vertical
Crest Width	25 ft

2. Quantity Computations:

Capacity = 103,000,000 yd^3

Embankment Volume[a]: 6,341,945 yd^3

Surface Area at Effective Depth:[a]
28,332,800 ft^2

Land Area Required[a]:

Surface area at effective depth + bench and embankment area

615 acres + 23.5 acres = 638.5 acres

[a] Planimetered from preliminary design drawings.

Clearing and Grubbing

638.5 acres

Liner

$$638.5\ (\text{acres}) \times 43{,}560\ \left(\frac{\text{ft}^2}{\text{acre}}\right) \times \frac{1}{9}\ \left(\frac{\text{yd}^2}{\text{ft}^2}\right) = 3{,}090{,}340\ \text{yd}^2$$

3. Site Preparation Costs:

Clearing and Grubbing 638.5 ac x \$1,500/ac = \$ 957,750

Embankment: 6,341,945 yd^3 x \$5/yd^3 = 31,709,725

Liner 3,090,340 yd^2 x \$5.50/yd^2 = 16,996,870

Land 638.5 ac x \$1,500/ac = 957,750

Stripping and Stockpiling 6" Topsoil
515,057 yd3 x \$3/yd^3 = 1,545,171

Seeding 638.5 ac x \$1,000/ac = 638,500

Dam Appurtenances - \$100,000 lump sum = 100,000

Disposal Area Capital Cost = \$52,905,766

4. Site Operation Costs

a. Front End Loader (Catepillar 966C)

No. required on-site	1
Estimated life	7 years
Present cost	\$119,000/unit
Total Capital Cost of Units:	

Year	Capital Cost at 1 Unit Every 7 Years
1	\$ 119,000
7	210,647
14	372,875
21	660,042
28	1,168,365
TOTAL	\$2,530,929

b. Dredge (Mud Cat: SP-810)

No. required on-site	1
Estimated life	10 years
Present cost	$75,100
Total Capital Cost of Units:	

Year	Capital Cost at 1 Unit Every 10 Years
1	$ 75,100
10	169,800
20	383,900
30	868,000
TOTAL	$1,496,800

c. Oiler

Hourly wages	$6.375/hour
Overhead rate	2.0
Total wage cost/hour	$12.75
On-site hours/year	1,000
Yearly cost	$12,750

d. Operator

Hourly wages	$10.08
Overhead rate	2.0
Total wage cost/hour	$20.16
On-site hours/year	2,000
Yearly cost	$40,320

e. Fuel

Fuel consumption rate	14.9 gal/hour [8.4 + 6.5 = 14.9]
Fuel cost	$1.00 gallon
Yearly operating hours	1,000
Yearly fuel cost	$14,900

f. Maintenance and Lubrication

Cost	$1.16/hr (0.50 + 0.66 = 1.16)
Yearly operating hours	1,000
Yearly Cost	$1,160

g. Site Operation Capital Cost

Front-end loader	$2,530,929
Dredge	1,596,800
TOTAL	$4,028,000

h. Site Operation Annual Cost[b]

Oiler	$12,750
Operator	40,032
Fuel	14,900
Lube & Misc	1,160
TOTAL	$69,130

i. Site operation 35 years, annual cost @ 8.5% inflation[b]

$$\$69,310 \left[\frac{(1+0.085)^{35+1} \quad -1}{0.085} -1\right] = \$14,448,000$$

---

[b] For present worth analysis, only the initial equipment purchase is considered a capital expense. Therefore:
O&M Capital: 119,000 + 75,100 = $194,100
35 year O&M: 14,448,000 + [$4,028,000-194,000] = $18,282,000

---

5. Transportation Costs

Assumptions:

Useful Life	35 years
Power Station Load Factor	80 Percent
Pumping Units	
Transport (centrifugal slurry)	7
Return (centrifugal slurry)	4
Transport:	
Pump	24 hours/day
Velocity	12 feet/sec
Slurry	10 percent

Pipes designed for maximum flow

Maximum flow = 2 x average flow with 1 out of service.

2600 MW plant has 104,076,020 yds^3 of ash for wet disposal over 35 years.

a. Daily Ash Production

$$104{,}076{,}200\ (\text{yds3}) \times \frac{1}{35}\ \frac{1}{(\text{yrs})} \times \frac{1}{365}\ \frac{(\text{yr})}{(\text{days})} \times \frac{27}{1}\ \frac{(\text{ft}^3)}{(\text{yd}^3)} = 219{,}950\ (\text{ft}^3/\text{day})$$

b. Maximum flow at 10 percent slurry

$$219{,}950\ \left(\frac{\text{ft}^3}{\text{day}}\right) \times 2 \times 10 = 4{,}399{,}000\ \left(\frac{\text{ft}^3}{\text{day}}\right)$$

c. Transport Lines

Pipe Cross Sectional Area

$$A = \frac{Q}{V} = \frac{4{,}399{,}000\ \left(\frac{\text{ft}}{\text{day}}\right) \times \frac{1\ (\text{day})}{24 (\text{hours})}\ \frac{1}{3600} \times \frac{(\text{hr})}{(\text{sec})}}{\frac{12\ (\text{ft})}{(\text{sec})}} = 4.25\ (\text{ft}^2)$$

∴ Need six 12-inch diameter pipes, with 1 spare. Total need is 7 pipes (7x5280 = 36,960 feet x \$15.74/foot = \$578,000).

d. Return Lines

Assume only water transport back to plant:

$$0.9 \times 4{,}399{,}000\ \left(\frac{\text{ft}^3}{\text{day}}\right) = 3{,}959{,}000\ \left(\frac{\text{ft}^3}{\text{day}}\right)$$

Pipe Cross Sectional Area

$$A = \frac{Q}{V} = \frac{3{,}959{,}000\ \left(\frac{\text{ft}^3}{\text{day}}\right) \times \frac{1}{24}\ \left(\frac{\text{day}}{\text{hr}}\right) \times \frac{1}{3600}\ \left(\frac{\text{hr}}{\text{sec}}\right)}{12\ \left(\frac{\text{ft}}{\text{sec}}\right)} = 3.80\ (\text{ft}^2)$$

∴ Need three 16-inch diameter pipes, with 1 spare. Total need is for 4 pipes (4x5280 = 21,120 x \$24.80/foot = \$523,776).

e. Capital Cost

Transport Pumps

No. required	7
Estimated Life	4 years
Present cost	\$5,209/unit

Total capital cost of units

Year 1	$ 35,463
4	50,533
8	70,031
12	97,053
16	134,502
20	186,401
24	258,325
28	358,002
32	596,140
TOTAL	$1,687,450

However, only the initial purchase of 7 pumps is considered to be a capital cost under present worth analysis. Therefore, only $36,463 is considered a capital cost for the present worth analysis.

Return pumps

No. required	4
Estimated life	20 years
Present cost	$12,834/unit

Total Capital Cost of Units

Year 1	51,336
20	262,432
TOTAL	313,768

However, only initial purchase of 4 pumps is considered to be a capital cost under present worth analysis.

Transport Lines

No. required	7
Size	12 inch diameter
Estimated life	4 years
Present cost	578,054

Total capital cost of lines

Year 1	$ 578,054
4	801,101
8	1,110,213
12	1,538,598
16	2,132,280
20	2,955,039
24	4,095,266
28	5,675,460
32	7,865,386
TOTAL	$26,751,397

However, only $578,054 is considered a capital cost for present worth analysis.

Return lines

No. required	4
Size	16 inch diameter
Estimated life	20 years
Present cost	523,776

Total capital cost of lines

Year 1	$ 523,776
20	2,667,567
TOTAL	$3,201,343

However, only $523,776 is considered a capital cost for present worth analysis.

Ash Transport Capital Cost

Item	Total Capital Cost	Present Worth Capital Cost
Transport Pumps	$ 1,687,450	$ 36,463
Return Pumps	313,768	51,336
Transport Lines	26,751,397	578,054
Return Lines	3,281,343	523,776
TOTAL	$31,951,000	$1,189,629

f. Operation and Maintenance Cost:

Pump Operation Cost

$$\left(\frac{\text{hp}}{\text{pump}}\right) \times 24 \left(\frac{\text{hr}}{\text{day}}\right) \times 365 \left(\frac{\text{day}}{\text{year}}\right) \times 0.7457 \left(\frac{\text{kw-hr}}{\text{hp-hr}}\right) = 6532 \left(\frac{\text{kw-hr}}{\text{year-hp}}\right)$$

Transport pumps:	7 @ 125 hp
Return pumps:	4 @ 150 hp

Pumping Cost

Transport : 7x125x6532x.0208 = $118,800
Return: 4x150x6532x.0208 = 81,500

Total Annual Pump Cost $200,300

Total 35 Year Pumping Cost

Transport: $118,800x209.1 $24,800,000
Return: 81,500x209.1 17,000,000

Total $41,800,00

35 YEAR O&M COST

	Total System Cost	Present Worth Cost (includes replacements)
Transport Pumps		
Operation	$24,800,000[e]	$24,800,000[e]
Replacement		1,651,000[c]
TOTAL	$24,800,000	$26,451,000
Return Pumps		
Operation	$17,000,000[e]	$17,000,000[e]
Replacement		272,000[c]
TOTAL	$17,000,000	$17,272,000
Transport Lines	[d]	$26,173,000[c]
Return Lines	[d]	2,678,000[c]
TOTAL	$41,800,000	$72,574,000

[c] Replacement cost, see ash transport capital cost for details.

[d] O&M was considered as replacement and became part of the capital cost.

[e] Pump O&M was considered well defined by the cost of electricity for operation. These costs were computed at a rate of $0.208/kw-hr.

Note: Pump maintenance could be included with the cost of pump O&M; however, its cost is small compared to the cost of electricity. For example, if annual pump maintenance is taken at 15% of the pump capital cost, then:

0.15 x (36,463 + 51,336) = $13,169/year

or

$$\$13,169 \left[\frac{(1+0.085)^{35+1}-1}{0.085} -1\right] = \$2,752,321 \text{ (total 35 year cost)}$$

Pump maintanance then provides only 6% of the cost of electricity which is well within the accuracy of this analysis.

Other maintenance items which could be included are the costs of pipeline maintenance and water treatment for the recycle water. It was assumed that a replacement period of 4 years for the transport lines and 20 years for the return lines would be adequate for the maintenance requirements. However, although the total dollars are sufficient, they may be expended in various ways. If the lines become clogged due to salt buildup, then additional maintenance will be required but the life expectancy of the pipe will be increased. Various other options are possible; however, the ultimate costs are thought to be similar.

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6. In-Plant Handling System

Capital cost[f]
$8,500,000

([f]Manufacturers' data)

Operation and Maintenance Costs[g]
$1,445,000

$$\$1,445,000 \times \left[\frac{(1+0.085)^{35+1} -1}{0.085} -1\right] = 302,121,000$$

[g]17% of capital cost.

7. Total System Cost

Capital Cost

In-plant	$ 8,500,000
Transportation	31,954,000
Disposal area	52,906,000
TOTAL	$ 93,360,000
Weighted Cost of Capital	$ 724,100,000

Operation and Maintenance

In-plant	$ 302,121,000
Transportation	42,140,000
Disposal area	14,448,000
TOTAL	$ 358,709,000
TOTAL SYSTEM COST	$1,082,800,000

PRESENT WORTH ANALYSIS

Inflation rate:	8.5%
Cost of Capital	2.3%
Discount rate:	11%

Capital Cost

Disposal area (see pp. C-2)	$ 52,905,766
Front end loader (see pp. C-2) 119,000 [1+.84+.71+.60+.50]	434,350
Dredge (see pp. C-2) 75,100 [1+.78+.61+.48)	215,537
Transport pumps (see pp. C-5,6) 7x5209x[1+.91+.82+.74+.67+.61+.55+.50+.45]	227,893
Return pumps (see pp. C-6) 4x12,834x[1+.61]	82,650
Transport lines (see pp. C-6) 7x578,054x[1+.91+.82+.74+.67+.61+.55+.50+.45]	25,289,862
Return lines (see pp. C-7) 4x523,776x[1+.61]	3,373,117
In-plant handling system (see pp. C-8)	8,500,000
Total Capital Cost	$ 91,029,175

Note: Numbers in brackets [] are present worth factors based on the number of years to the expenditure and a 2.3% cost of capital.

Operation and Maintenance (O&M) Cost

Disposal area (see pp. C-3)

Oiler	$12,750/year
Operator	40,320/year

Fuel	14,900/year	
Maint. and lubrication	1,160/year	
Total	$69,130/year (see pp. C-4)	
69,130 x 24.5[f]		$ 1,694,000

Transportation

Transport pumps:	$118,800/year (see pp. C-7)	
Return pumps:	81,500/year (see pp. C-8)	
Total	$200,300/year	
$200,300x24.5		$ 4,907,000

In-plant handling (see pp. C-8)

$1,445,000/year x 24.5	35,402,500
Total O&M Cost	$42,003,000
Present Worth	$133,032,170

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[f] Present worth factor for an annual expenditure over 35 years at a 2.3% cost of capital.